Increasing DryDev's Effectiveness and Efficiency through Probabilistic Decision Modelling

*Yvonne Tamba, Caroline Muchiri, Keith Shepherd,
Grace Muinga, Eike Luedeling*

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List of Abbreviations

AATF	African Agricultural Technology Foundation
ADRA	Adventist Development and Relief Agency
AIE	Applied Information Economics
ASAL	Arid and Semi-Arid Land
AWARD	African Women in Agricultural Research and Development
CGIAR	Consultative Group on International Agricultural Research
DryDev	Drylands Development Programme
DTC	Drought Tolerant crops
HQ	Headquarters
ICRAF	World Agroforestry Centre
Kes	Kenya Shilling
NPV	Net Present Value
PLS	Partial Least Squares regression
SME	Subject Matter Expert
SNV	Netherlands Development Organization
USD	United States Dollar
VIP	Variable Importance in the Projection
VOI	Value of Information

Abstract

This working paper describes the Decision Analysis work done on the Drylands Development Programme (DryDev) in Sub-Saharan Africa. The programme was designed to address water management, food security and rural economic development in the drylands of Kenya, Ethiopia, Burkina Faso, Mali and Niger. The initiative was geared towards supporting the transition of smallholder households from subsistence farming and reliance on emergency aid towards more sustainable agribusiness enterprises.

Decision Analysis was used as a quantitative ex-ante impact assessment tool to prioritize interventions based on their projected impacts. The assessment simulated the potential of four interventions in six project sites of Eastern Kenya, incorporating risk and uncertainty in decision modelling. The result delivered to the decision makers was a range of plausible outcomes from a cost benefit analysis and a description of the variables with the highest critical uncertainties whose measurement would most facilitate decision-making. This paper describes the modelling process, which was both participatory and probabilistic, for each intervention. It gives details on the quantitative approach used for each of the four interventions separately, highlighting the benefit, cost and risk variables and the interactions between them. It then discusses the results of each decision model and from these makes recommendations to the decision makers. The penultimate section highlights the limitations and constraints faced by the analysis, and this is followed by general conclusions.

The DryDev Programme is funded by the Netherlands' Ministry of Foreign Affairs, with ICRAF as the lead implementing agency and SNV, CARITAS, ADRA and World Vision as implementing partners.

Key words: Net Present Value; Monte Carlo simulation; value of information; calibration; decision analysis; decision model

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The Drylands Development (DryDev) Programme

Genesis

Drylands in the developing world account for over 40% of the total earth surface area and are home to approximately 2.5 billion people, the majority of whom are poor farmers (Sanders and Devlin, 2013). The Dryland agro-ecological zone, which comprises both arid and semi-arid ecosystems, is characterized by strong rainfall variability, recurrent but unpredictable droughts, high temperatures and low soil fertility. The prevailing agro-ecological climate contributes towards an unsustainable environment often featuring poor agricultural productivity, water scarcity, land degradation, high poverty levels and unemployment. Despite the constraints present in this harsh climatic region, agriculture is a key economic activity. Faced with highly variable rainfall and water insecurity, farmers are limited to subsistence-oriented agriculture (Bantilan et al., 2006). The challenge therefore, for inhabitants of these regions as well as for the science community, is to sustainably improve the livelihoods of smallholder farmers residing in drylands.

Objective

The Drylands Development Programme is designed to address water management, food security and rural economic development in the drylands of Kenya, Ethiopia, Burkina Faso, Mali and Niger. The programme targets over 227,000 farmers in these five countries and is geared towards supporting the transition of smallholder households from subsistence farming and reliance on emergency aid towards more sustainable agribusiness enterprises. The programme is funded by the Netherlands' Ministry of Foreign Affairs, with ICRAF as the lead implementing agency. Implementing partners include SNV, CARITAS, ADRA and World Vision.

Project sites

The programme is implemented in dryland areas of the five target countries — Ethiopia, Kenya, Mali, Burkina Faso and Niger. This report will be centred on the dryland areas of Kenya, as this was the geographical focus of the analyses. The programme targeted areas commonly classified as semi-arid. In Kenya, this zone covers about 43% of the total land area, which is characterized by long dry spells and at times pronounced drought periods of moderate to high intensity.

The areas of operation in Eastern Kenya covered six sites across three counties: Lower Yatta (Kanyangi) and Mwingi (Waita) in Kitui County, Kalawa and Mtito Andei in Makueni County and Yatta and Mwala in Machakos County (Figure 1). The three counties, Makueni, Machakos and Kitui have a combined population of 2,995,820¹. They fall under the Arid and Semi-Arid Lands (ASALS) and receive annual rainfall of 400-800mm.

Socio-economic studies carried out for the purpose of the programme found that the area is characterized by an aggregate poverty level (proportion of population living on under USD 1.25 a day) of 62.8%, an average household size of six people per household and average land size

¹ Information obtained from characterization studies carried out by implementing partners.

varying from 2.22 acres to 8.77 acres. The main economic activity in the area is subsistence farming.

Decision Analysis in the DryDev Programme

Increasing effectiveness and efficiency through probabilistic decision modelling

Figure 1. Project sites in Kitui, Machakos and Makueni counties (EFSEK, 2014)

A World Bank report published in 2010 pointed out that there has been a decline in the use of cost-benefit analysis to justify their investment projects, despite cost-benefit analysis being critical for making wise investments, especially in agricultural projects on the African continent (World Bank, 2010). Decisions informed by return on investment analysis are most likely to have long-term, sustainable impacts, maximizing returns from limited resources. The DryDev Programme saw the need to apply robust analysis of the likely impacts of the interventions on livelihoods of the community and thus improve the capacity of policy makers to make decisions.

This analysis would consequently improve the quality of the decisions made regarding implementation of the programme's activities for sustainable impact. ICRAF's Decision Analysis Unit was therefore commissioned to conduct a business case study that considered the benefits, costs and risks for the programme's activities in Kenya.

Decision modelling is an approach used and developed by ICRAF to prioritize interventions based on their likely impacts (Luedeling and Shepherd, 2016). This is achieved by conducting

ex-ante impact assessments using quantitative impact pathways and probabilistic estimates of all relevant benefits, costs and risks. The decision analysis approach is based on the principles of Applied Information Economics (AIE; Hubbard, 2014), which refers to a process that incorporates risk and uncertainty in decision models by including calibrated estimates, quantifying risks, identifying knowledge gaps, computing the value of additional information and running Monte Carlo simulations (Luedeling et al., 2015).

These principles of AIE were applied to the DryDev Programme in an effort to improve the capacity of decision makers and stakeholders. The decision model was shaped as a robust cost-benefit analysis that computed the benefit streams expected from the programme while accounting for the impact of uncertainties about future trends and the limiting impact of risks on expected benefits. The Net Present Value (NPV) of the benefit streams was determined by discounting the benefits and costs. The case for NPV lies in incorporating the value of managing an investment into the initial evaluation and decision to take up the investment (Tauer, 2000). To this end, the model was both probabilistic and participatory, employing expert knowledge from implementing stakeholders and eliciting from them range estimates and probability distributions for the purpose of model parameterization.

To enable subject matter experts to quantify their uncertainty, they received some calibration training, which gave them the skills to give estimates of their 90% confidence intervals for variables of interest. Specifying variable values as ranges and probability distributions as opposed to point estimates allows for appreciation of the full range of plausible outcomes and identification of the most critical knowledge gaps. The parameters were then plugged into the model which ran a Monte Carlo simulation to generate projections of intervention impact.

Interventions selected for modelling

The DryDev Programme had identified a series of ‘quick-win’ interventions that were to be pursued in the initial stages of the project. From a list of about 20 quick-wins, four were selected for detailed decision modelling:

1. Promotion of Drought Tolerant Crops (DTCs) and seed bulking
2. Establishment of collective marketing and market linkages for farm produce and seedlings
3. Promotion of high-value trees (Mangoes, Melia and any other trees)
4. Establishment of water harvesting structures.

Project partners selected these four interventions, because they considered their impacts as particularly uncertain. Time and budget constraints prevented analysis of more than four interventions.

The modelling process

After the interventions to be analysed were identified, the modelling process started off with webinar trainings, in which project partners were introduced to AIE and the principles underlying the approach. This was followed by another seminar that aimed at improving the participants’

ability to make range estimates of uncertain variables that reflect their true level of certainty (calibration training). These online training seminars were conducted on 27-28 May 2014. All trained participants were then invited to a 2-day modelling session at Tara Suites in Gigiri (Nairobi, Kenya) on the 24-25 June 2014. The aim of this modelling workshop was to identify costs, benefits and risks related to the four interventions and draw out cause-effect relationships between these items. These relationships were then used by the analysts to build the four models. The next round of partner consultations consisted of focus group visits conducted on 12-18 May 2015. The decision analysts visited the partners at their respective offices to discuss the models as they were at the time, to request feedback on the progress made, and to elicit quantitative range estimates for model variables. Having received feedback from the partners on the structure of the model, the team went ahead to run the parameterized models and begin to analyse the results.

On 2 October 2015, project partners were invited to ICRAF headquarters for a workshop, where they presented and discussed the results of the model runs. During the event, the partners who were present expressed interest in the results presented but ultimately concluded that they were not readily useable given the structural changes that had taken place in the project's management and the overhaul in the planned outcomes.

Keeping the project partners informed of the progress and the shape of the model at different times was an integral part of the process as it intended to build a sense of ownership of the model and the eventual results and recommendations from the process. The team's attempts to achieve this faced challenges when it came to engaging the partners who were often out in the field and unreachable for comment. Staff turnover within the modelling team was also a constraint to consistent communication.

Key Modelling Concepts Defined

To adequately describe the modelling method and thus the results from the model, some key concepts need to be defined:

Utility

In an area where an average of 9.6% of the population rely on food aid in dry months and 62.8% of the population live below the poverty line, more emphasis is placed on benefits to farmers living below the poverty line than to well-off farmers. The project's objective of improving the lives of the poor indicates that the stakeholders value benefits accruing to poor farmers more highly than to farmers who are already well off. The modelling team dubbed this preference 'utility'. To capture it, demographic variables were added to the model portraying three different farmer wealth classes: the wealthy, the middle-income and the poor. Each wealth class was characterized by average farm size and the percentage of total farms that fall into each class. Both benefit and cost valuations were subject to utility preferences as shown below.

Benefits

Rich farmer benefits

*= Total farmer benefits * percentage of total no. of rich farmers*

Middle income farmer benefits

= Total farmer benefits

** percentage of total no. of middle income farmers*

Poor farmer benefits

*= Total farmer benefits * percentage of total no. of poor farmers*

Costs

*Rich farmer costs = Cost to farmer * percentage of total no. of rich farmers*

Middle income farmer costs

= Cost to farmer

** percentage of total no. of middle income farmers*

*Poor farmer costs = Cost to farmer * percentage of total no. of poor farmers*

Discounting future benefits and costs

In order to value future benefits and costs, the Net Present Value of all costs and benefits was computed. This calculation assumed that costs and benefits are reduced by a fixed percentage (discount rate) for each year in the future. The discount rate expresses the degree to which stakeholders would value immediate benefits more highly than those they would receive at a later date. This rate is normally relatively low (~5%) for conservative investors investing in a fairly secure activity, but can be very high (>10%, or even >30%) for poor farmers, for whom delaying benefits may mean going hungry in the short-term. Discounting future costs and benefits is a common economic practice, but it raised the question about what discount rates are appropriate for the various stakeholders. These were difficult to estimate, but were seen to have a critical

impact on projected project outcomes. Consequently, discount rates for each stakeholder were explicitly stated as uncertain inputs to the model

The Value of Information

The Value of Information measure refers to the economic cost of reducing uncertainty in decision-making. Uncertainty and the corresponding risks are inherent in all decisions, but most especially where the decision maker has to choose among a number of solutions. The main aim of the decision analysis process is to enhance evidence-based decision-making. There is an opportunity cost to a decision made since benefits are lost when a decision is made for intervention 1 over intervention 2. This opportunity cost in addition to the amount of money put into intervention 1 over intervention 2 is the cost of being wrong. The cost of being wrong multiplied by the likelihood of being wrong makes up the Value of Information.

Procedures for calculating the Value of Information in strict accordance with these principles were not yet included in the analysis package at the time the analyses were done. We filled this gap by using an alternative measure – the Variable Importance in the Projection (VIP) statistic of Partial Least Squares regression – which is also capable of highlighting the variables that most affect decision outcomes. Unlike the Value of Information, which is often zero for most variables, all uncertain variables are assigned a VIP score. A decision is then needed on a minimum VIP score, above which variables are considered important. For the purpose of our analysis, this threshold for distinguishing important from unimportant variables was set to 0.8 in accordance with common analysis protocols. Variables with VIP scores above 0.8 are then ranked in descending order. In illustrations, independent variables that were negatively correlated with the NPV are indicated in red, while those with positive correlations are green.

Costing

The cost of each intervention was taken as the summation of the costs for all individual activities. The costs incurred over the duration of the intervention would mainly accrue to the implementing body, but adopting farmers may also incur some costs that will affect their economic bottom line. Therefore, costs to both the implementer and farmers were captured in the model. Utility preferences were also applied to farmer costs on the basis that a dollar going to a poor farmer has greater value than a dollar going to a wealthy farmer. On the other hand, a dollar spent by a poor farmer would cost more to the farmer than a dollar spent by a wealthy farmer. All costs were estimated per year for the number of relevant years for the project.

Risks

From the discussion with implementing farmers at the modelling workshop there were three risk categories based on whether they would cause the project to fail or just underperform. The estimate values for risks were given as probabilities – possible chances of occurrence (numbers between 0 and 1).

- 1) *Factors that would cause the project to fail after some time:* These factors could cause the project to fail any year after implementation. They cause the project to end with no further benefits. The question here was not to estimate the percentage chance of

occurrence, since occurrence in the area does not guarantee that it will affect the project. The main question here was, ‘What is the probability that this risk factor would cause the project to fail?’ We used the estimates of these risks to compute the chance of project success.

- 2) *Factors that would reduce performance in some years:* These factors would occur in some years but not others, and therefore would result in underperformance of the project in those years they occur, but not have a continuous effect on the initiative. If these situations persist, they may cause farmers to dis-adopt the innovative practices.
- 3) *Factors that would reduce performance of the project in all years:* These factors wouldn’t stop the project, but would reduce expected benefits, and if present, would recur every year. They were expressed by a ‘benefit scaling factor’, which determined by how much the project would underperform. The subject matter experts were asked to estimate the annual possibility of occurrence and the magnitude of the effect on the project benefits.

These risk factors were ultimately applied to adjust benefit streams to determine the likely impact of these risks on project outcome. Since there were many risk factors for subject matter experts to consider, we noticed that there was a high chance that partners would overestimate individual risks which could greatly distort the results. To account for this, another risk variable was added, which capped the interventions’ ‘total risk’ at a percentage corresponding to the highest plausible chance that the project would fail. This variable would scale back risk factors if the factors added up to more than the total risk.

Model outputs

The simulation model described above was used to produce two different types of analysis outputs:

- 1) Returns to farmer (Farmer NPV)
- 2) The Value of Information (as expressed by the VIP scores)

Farmer NPV summarizes the total returns to the farmers over a 20-year period, given the benefits, costs and risks attributable to farmers. The simulation period of 20 years was chosen to project returns from the initiative in the medium to long term. The probabilistic models returned a range of results which were represented in histograms illustrating the expected returns. For each category of output, the model also applied a computation of Value of Information and returned a bar graph representing the knowledge gaps identified. These results present the uncertainty of the project partners with regards to likely decision outcomes and are the variables on which further measurement and close scrutiny is recommended.

Intervention 1: Promotion of Drought-Tolerant Crops

Farmers in the project sites are already familiar with drought-tolerant crops (DTCs) suitable for the climatic region. They already grow crops such as pigeon peas, green grams and cow peas, but tend to use local seeds more often than they do improved varieties. The aim of the DryDev Programme in this intervention was to promote the use of improved varieties. Land sizes show little variation across the six sites, with farmers cultivating between 2.2 and 3.5 acres and growing a combination of 3-5 of six major crops (maize, mangoes, pigeon peas, cow peas, lentils and green grams). We analysed the productivity and profitability of pigeon peas, cow peas and green grams.

Table 1: Major crops grown

Project Site	Major Crops			
		Pigeon Peas	Cow Peas	Green Grams
Mtito Andei	Acreage	0.19	0.45	0.25
	Productivity/acre	271kg	312kg	166kg
	Potential yield/acre	550kg	500kg	270kg
	% achievement	50	62.4	61
Kalawa	Acreage	0.14	0.2	0.16
	Productivity/acre	70kg	104kg	132kg
	Potential yield/acre	550kg	500kg	270kg
	% achievement	13	21	49
Kanyangi	Acreage	0.1	0.1	0.12
	Productivity/acre	117kg	86kg	58kg
	Potential yield/acre	550kg	500kg	270kg
	% achievement	21	17	21.5
Waita	Acreage	0.4	0.2	0.1
	Productivity/acre	50kg	30kg	103kg
	Potential yield/acre	550kg	500kg	270kg
	% achievement	9	5.45	38.1
Yatta	Acreage	0.2	0.2	0.4
	Productivity/acre	150kg	165kg	128kg
	Potential yield/acre	550kg	500kg	270kg
	% achievement	27	33	47
Mwala	Acreage	0.9	0.9	0.1
	Productivity/acre	132kg	110kg	106kg
	Potential yield/acre	550kg	500kg	270kg
	% achievement	24	20	39

Source: EFSEK baseline survey report

Benefits accruing from the adoption of DTCs

The programme's targeted beneficiaries can only receive the benefits from DTCs if they actually adopt the intervention. Given that they were currently using local varieties of pigeon peas, cow peas and green grams (referred to here as traditional crops), the revenue benefits from DTCs were compared to those of traditional crops, separately considering conditions of drought, above-normal rainfall and normal rainfall. This distinction was considered necessary, because the

advantages of drought-tolerant crops were likely to have a greater impact during drought than during years with normal or above average rainfall.

To this effect, the gross income from the production of DTCs and traditional crops was calculated. These calculations were done for each year i (ranging up to the user-specified duration of the simulation) and for three types of weather w (drought, normal and above average rainfall):

$$\begin{aligned} \text{Farm production}_{i,w} \\ = \text{production in kg}_{i,w} * \text{farm area} * (1 - \text{postharvest losses}) * (1 \\ - \text{preharvest losses}) \end{aligned}$$

For each year of the simulation, the respective weather was randomly selected, based on user-specified probabilities of drought and flood situations. Only the aggregate farm production values corresponding to the weather in a given year were used for further simulations. From these values, the household consumption was then subtracted to obtain the production surplus:

$$\text{Production surplus}_i = \text{farm production}_i - \text{household consumption}_i$$

Farm revenue from crop sales was calculated for each year by multiplying the production surplus by the produce price, which was sampled from a distribution depending on the weather in the given year (considering that prices may be increased in drought or above average rainfall years compared to in normal years due a reduced overall supply).

$$\text{Revenue}_i = \text{production surplus}_i * \text{price of produce}_{i, \text{considering weather}}$$

The benefit from adoption of the DTCs was then computed as the difference between farm revenues for DTCs and traditional crops:

$$\text{i. } \text{Crop sale benefits}_i = \text{revenue from DTC}_i - \text{revenue from traditional crops}_i$$

The crop sale benefits were a major category of benefits from this intervention. The other major benefit of promoting improved varieties of drought-resistant crops was the potential for improving food security in the semi-arid region. Indicators of food security would be health benefits of improved nutrition levels in the short term as well as future improvements in productivity.

These benefits were further disaggregated as follows:

- ii. *Improved food security = reduced impact of malnutrition + improved labour productivity*
with
- iii. *Reduced impact of malnutrition = savings on health costs + reduced reliance on food relief + more productive labour force*
and

- iv. *Improved future productivity =*
benefits from improved productive potential of the next generation +
benefits from improved school performance

For these benefits, subject matter experts were required to give range estimates for:

- Savings on health costs
- Benefits from reduced reliance on relief food
- Benefits from increased labour force
- Benefits from increased productive potential of the next generation
- Benefits from increased school performance

The monetary value of these benefits were given per farmer and listed per year, with exclusion of benefits from future productivity which were listed for all the years the simulation was run. Overall project benefits were then calculated by multiplying by the number of adopters.

The number of adopters was represented as depending on the portfolio of communication strategies used for this intervention, the adoption rate for each strategy and the number of farmers targeted through each mode of communication. Workshops, trade fairs (*barazas*) and farmer-to-farmer interactions were identified as the modes of communication to be used.

Number of adopters

$$\begin{aligned}
 &= \text{farmers targeted by trade fairs} * \text{adoption rate through trade fairs} \\
 &+ \text{farmers targeted through workshops} \\
 &* \text{adoption rate through workshops} \\
 &+ \text{farmers targeted through farmer to farmer interaction} \\
 &* \text{adoption rate of farmer to farmer interactions}
 \end{aligned}$$

After obtaining the benefits from the project for each category (crop revenue, plus the items listed above), they were multiplied by the possible number of adopters. Total project benefits per year were determined by adding all individual benefits:

Total benefits_i

$$\begin{aligned}
 &= \text{revenue from sale}_i + \text{benefits from reduced malnutrition impact}_i \\
 &+ \text{benefits from improved productivity}
 \end{aligned}$$

$$\text{Overall benefits} = \text{total benefits}_i * \text{number of adopters}$$

To capture demography-specific benefit streams:

$$\text{Rich farmer benefits} = \text{overall benefits} * \text{share of all farmers that are rich}$$

Middle – income farmer benefits

$$\begin{aligned}
 &= \text{overall benefits} * \text{share of all farmers that are middle} \\
 &- \text{income earners}
 \end{aligned}$$

$$\text{Poor farmer benefits} = \text{overall benefits} * \text{share of all farmers that are poor}$$

Costs incurred through adoption of DTCs

The total cost function for the adoption of DTCs was defined as:

$$\text{Total cost} = \text{cost to farmers} + \text{cost to implementer}$$

The two elements of this equation were composed as follows:

$$\text{Cost to farmers} = \text{farmer input cost} + \text{farmer transport cost to and from training}$$

$$\text{Costs to the implementer}$$

$$= \text{cost of salaries} + \text{cost of training and advertisement}$$

$$+ \text{cost of materials for value chain development}$$

$$+ \text{value chain development transport cost}$$

For project implementers, the cost of salaries was calculated from the number of staff allocated to this intervention, as well as their salary level. The costs of materials and transport related to value chain development were elicited as direct estimates from the project team.

Costs for training and advertisement were disaggregated by communication strategy, since the cost structure of, say, communication through workshops is fundamentally different from trade fairs while farmer interactions incurred no costs.

$$\text{Cost of training and advertisement}$$

$$= \text{investment per targeted farmer through trade fairs}$$

$$* \text{farmers targeted through trade fairs}$$

$$+ \text{investment per targeted farmer through workshops}$$

$$* \text{farmers targeted through workshops}$$

For all the annual cost items, experts were requested to provide the long-term average, as well as a coefficient of variation that expresses how actual annual values were expected to vary around the mean. These estimates were then used to generate time series that truly represented the estimated means while varying from year to year as prescribed by the coefficient of variation.

Possible risks

For this intervention, the greatest risks were those that would affect the adoption rate of DTCs. The risks identified at the workshop were classified into three groups:

1. Factors that could cause project failure: This ‘killer factor’ category only included one type of risk:
 - Political instability
2. Factors that could cause dis-adoption: Those that could cause farmers to reject the species of drought-tolerant crops being promoted:
 - Lack of market for value chain commodities
 - Lack of synergy and cooperation with other external partners
 - Misalignment with government policies
 - Poor project management.

These factors which could lead to dis-adoption were lumped into two categories:

a. Institutional risks

Misalignment with government policies, lack of synergy and cooperation with partners and poor project management were risks whose occurrence would affect the implementation process, hence institutional risks. They were estimated by the likelihood of any of these issues arising with the variable institutional risks and the damage expected (extent of dis-adoption) in case of occurrence:

Institutional risks

$$= (1 - \text{chance of institutional risks occurring}) * (1 - \text{rate of disadoption due to institutional risk})$$

b. On-farm risks

The same treatment was performed on on-farm risks, which constituted the risks directly affecting the farmer, such as labour constraints and market factors. The extent of dis-adoption due to these factors and the likelihood of occurrence of these factors were multiplied to obtain the chance that the project would be successful:

On farm risks

$$= (1 - \text{chance of onfarm risk occurrence}) * (1 - \text{rate of disadoption due to on farm risks})$$

3. Factors that could reduce performance of the project: Situations that, if they occurred, would not hinder the progress of the project, but would reduce the value of expected benefits and hence reduce the scale of success of the initiative:

- Low supply of inputs (seeds and fertilizer)
- Inadequate access to credit facilities for farmers
- Poor quality and inaccessible extension services
- General economic uncertainty/inflation.

According to these considerations, the chance of project success was defined as

Project Success

$$= 1 - \text{risk of political instability} * \text{institutional risks} * \text{on farm risks}$$

The ‘benefit scaling factor’ was computed to determine how far the benefits would fall below expected benefits.

Benefit scaling factor

$$\begin{aligned} &= (1 - \text{losses due to low supply of inputs}) \\ &* (1 - \text{losses due to lack of credit facilities for farmers}) \\ &* (1 - \text{losses due to poor quality and inaccessible extension services}) \\ &* (1 - \text{losses due to general economic uncertainty or inflation}) \end{aligned}$$

Model outputs

The model was designed to simulate the impact of the intervention on the stakeholders with the prevailing uncertainties. As a result, decision makers could be informed about plausible outcomes of the intervention and about the knowledge gaps whose measurement would most facilitate decision-making.

The projections of discounted returns accruing to adopting farmers were promising and indicated that the possibilities of gain were higher than the possibilities of loss (Table 2).

Table 2: Summary of returns from introducing DTCs

NPV	0%	25%	50%	75%	100%	Mean	Chance of loss
Wealthy farmer NPV	(52,000)	900,000	1,300,000	1,800,000	7,500,000	1,400,000	0.005
Middle-income farmer NPV	(260,000)	360,000	650,000	1,100,000	4,200,000	800,000	0.015
Poor farmer NPV	(380,000)	(19,000)	91,000	240,000	1,800,000	140,000	0.302

Returns to poor farmers

The distribution on the histogram (Figure 2) indicates that on average, farmers cultivating on land less than 1.5 ha could realize gains of up to Kes 1.8 million or losses as high as Kes 400,000 with a 32% chance of loss. Note that these figures are totals for returns over the model's simulation period of 15 years.

Figure 2: DTC-simulated NPV for poor farmers

Uncertain variables: poor farmers

Variables contributing to productivity of the drought-tolerant crops especially in normal weather – when there is neither excessive rainfall nor drought – were at the top of the list of important uncertain variables (Figure 3). Farm sizes, yields in normal weather, quantity of pre-harvest and post-harvest losses and the quality of extension services affect the farmers’ crop yields and subsequently, profits.

To mitigate loss risks due to uncertainty, it is recommended that these factors be measured further or continually monitored during implementation.

Figure 3: Uncertain variables limiting the precision of outcomes simulated in the DTC model (Poor farmer category)

Returns to middle-income farmers

Average returns to middle-income farmers owning and using 3-6 ha would fall in the region of Kes. 800,000. Our 90% confidence interval for cumulative earnings over the 15-year period is a range of Kes 260,000 to Kes 4.2 million (Figure 4).

Figure 4: DTC simulated NPV for middle-income farmer category

Uncertain variables: middle-income farmers

As with the poor farmers, the variables that were most uncertain for middle-income farmers were related to the yield and income productivity of farms: the yields of DTC per hectare, the price per kg in normal weather, the extent of harvest losses, and the farmers' discount rates (Figure 5).

Figure 5: Uncertain variables limiting the precision of outcomes simulated from DTC model (Middle-income farmer category)

Returns to wealthy farmers

It is expected that the probability of loss for wealthy farmers is almost non-existent, at 0.5%.

Total income is estimated at between Kes 52,000 and Kes 7.5 million over the simulation period of 15 years (Figure 6).

Figure 6: DTC simulated NPV for wealthy farmer

Uncertain variables: wealthy farmers

The least certain variables in this case are, as we have seen previously, mainly variables that affect productivity, i.e., size of the farm, yields per hectare, market price of yields in normal weather, quantity of pre-harvest losses and the risk of poor extension services (Figure 7).

Figure 7: Uncertain variables limiting the precision of outcomes simulated by DTC model (wealthy farmer category)

Conclusion

The analysis conducted on the potential returns from drought-tolerant crops to the community indicate that the likelihood of a negative outcome is minimal, less than 30%. From this we can effectively conclude that despite risk factors and uncertainty in variables, an investment in DTC is likely to succeed. However, to give clearer findings on what outcomes can be expected, the simulation requires that the programme put emphasis on specific variables, i.e., cultivated land size in the area, crop yields per parcel of cultivated land and the risk of receiving poor extension services.

Intervention 2: Collective Marketing and Market Linkages for Farm Produce and Seedlings

Market constraints are prevalent in rural areas and cause an imbalance in the distribution of income, especially among poorer farmers who lack the capacity to commercialize their production and the power to negotiate for fairer prices for their produce. This results in higher costs of production and lower incomes. Collective action through farmer co-operatives could lead to an increase in income by according farmers negotiating powers, creating an institutional arrangement that reduces the vulnerability of individual farmers, thus allowing smallholders to penetrate the market (Poulton et al., 2006).

The DryDev Programme, by recognizing the role of markets in agricultural successes, developed an intervention to establish collective marketing and market linkages for the participating farmers. This intervention involves identifying existing farmer marketing groups, exploring the potential for farmer-managed cooperatives, identifying commodities to be considered for value chain development and linking up farmer groups with financial service providers.

Benefits from collective marketing

Quantifiable benefits listed during the workshop included:

- Reduced transport costs per farmer
- Reduced input costs
- Increased financial access (% chance of using credit to expand farming activities) per farmer
- Reduction in post-harvest losses per farmer
- Increased influence on county/national policies
- Increased bargaining power.

Benefits such as increased financial access, increased influence on county/national policies and increased bargaining power were not as straightforward as, say, reduced input costs since they were not directly quantifiable. It was, however, possible to disaggregate them into contributing variables which were easier to estimate:

- Increased influence on policies should lead to improvements in farming business opportunities or other aspects of stakeholder livelihoods. It is possible to estimate the probability of a farmer group influencing a particular policy, the number of policies that can be influenced, and the amount of money to be gained from influencing a policy.
- Increased credit access may lead to growth and expansion of farming activities which is a quantifiable variable.
- Increased bargaining power enables farmers to get better prices for their produce, the prices being the variable to be estimated.

The income of a farmer who is a member of a co-operative was compared to the income of a farmer who is not, to estimate the direct income benefits of collective marketing. The difference

between these incomes was calculated for each year of the simulation (based on the user-specified duration).

Consideration was also made for farmers who could expand their farming activities given the possibility that availability of credit could motivate farmers to expand. The farm area was multiplied by probability and magnitude of expansion.

$$\text{Farm area} = \text{farm area} * (1 + \text{farm expansion}_{yes/no} * \text{percent farm area increase})$$

$$\text{Farm production}_i$$

$$= \text{yield per ha in kg}_i * \text{farm area} * (1 - \text{postharvest losses}) * (1 - \text{preharvest losses})$$

$$\text{Income } A_i = (\text{farm production}_i - \text{household consumption}_i) * \text{price without cooperative}_i$$

$$\text{Income } B_i = (\text{farm production}_i - \text{household consumption}_i) * \text{price with cooperative}_i$$

$$\text{incremental income}_i = \text{income } B_i - \text{income } A_i$$

Total benefits to the farmer:

$$\text{Total farmer benefits}_i$$

$$= \text{total incremental income}_i + \text{benefits from reduced input costs}_i$$

$$+ \text{benefits from reduction in post harvest losses}_i$$

$$+ \text{benefits from reduced transport costs}_i$$

$$+ \text{benefits from increased influence on county and national policies}_i$$

Benefits to the co-operative were computed as a multiple of individual farmer benefits and the size of the co-operative (number of members).

Total benefits to the co-operative:

$$\text{Benefits to cooperative}_i$$

$$= \text{total farmer benefits}_i$$

$$* \text{size of cooperative}(\text{number of members in a cooperative})$$

Costs of collective marketing

Costs to individual stakeholders were computed as follows:

$$\text{Cost to farmer}$$

$$= \text{membership fee} + \text{annual on-farm labour cost}$$

$$+ \text{annual cost of inputs}(\text{seeds, fertilizer, pesticides})$$

$$+ \text{transport cost to warehouse}$$

$$+ (\text{transport cost to and from training} \times \text{no. of trainings})$$

The utility preference applied to the farmer cost variable, i.e.,

*Rich farmers' costs = cost to farmer * share of all farmers that are rich*

Middle – income farmers' costs

*= cost to farmer * share of all farmers that are middle – income*

*Poor farmers' costs = cost to farmer * share of all farmers that are poor*

Costs to other stakeholders:

Cost to the cooperative

*= security fee + maintenance costs + cost of utilities for the warehouse
+ cost of equipment + other costs + cost of extension agents
+ insurance costs + transport cost for the cooperative
+ salaries for management staff + cost of loss from wastage
+ annual rent cost*

Cost to implementing agency

*= cost of training to the implementer + salaries to staff
* number of staff + sensitization costs*

- *Other costs = storage for different value chains*
- *Insurance costs = annual premiums*
- *Cost of training to the implementer = cost of materials, transport, etc.*
- *Sensitization costs = cost of media and advertisements*
- *Cost of loss from wastage = percentage chance of loss x value of loss*

Note that all costs were estimated per annum. The cost of loss from wastage is a calculated value derived from the multiplication of a percentage chance of loss and the value of this loss

Possible risks

1) Factors that could cause the project to fail:

- Risk of conflict among co-operative members
- Risk of political instability
- Risk of political interference

We used the estimates of these risks to compute the chance of project success. The equation was:

Project success

*= (1 – political instability) * (1 – conflict among members)
* (1 – political interference)*

2) Factors that could reduce performance of the project in all years:

- Poor governance within cooperative
- Lack of capacity of intermediaries
- Poor infrastructure (roads)

- Risk of poor market information
- Risk of inaccessible credit facilities

3) Factors that could reduce performance in some years:

These factors would occur in some years but not others, and therefore would cause underperformance of the project in those years they occur, but not have a continuous effect on the project:

- Side selling
- Loss of market/demand
- Unfavourable weather conditions
- Competition from other producers/cooperatives
- Glut (overproduction)
- Risk from the general economy/Inflation.

Subject matter experts were asked to estimate the annual possibility of occurrence and the magnitude of the effect on the project benefits.

Benefit scaler

$$\begin{aligned}
 &= (\text{occurrence of side selling} * (1 - \text{effect of side selling})) \\
 &* (\text{occurrence of loss of market demand} \\
 &* (1 - \text{effect of loss of market demand})) \\
 &* (\text{occurrence of unfavourable weather} * (1 \\
 &- \text{effect of unfavourable weather}) * (\text{occurrence of competition} \\
 &* (1 - \text{effect of competition})) \\
 &* (\text{occurrence of glut} * (1 - \text{effect of glut})) \\
 &* (\text{occurrence of inflation} * (1 - \text{effect of inflation}))
 \end{aligned}$$

Model outputs

The results from the analysis simulated expected returns for a period of 15 years which are outlined in Table 3.

Table 3: Summary of collective marketing model results (in tens of thousands)

NPV	0%	25%	50%	75%	100%	mean	Chance of gain
Poor farmer	(66)	(0.39)	48	1,50	21,00	1,10	0.74
Middle-income farmer	-	93	1,20	1,60	3,50	1,30	0.99
Wealthy farmer	-	1,90	2,30	2,90	6,00	2,40	0.99
Cooperative	-	-	660,00	1,500,00	6,700,00	910,00	0.74

Returns to poor farmers

Figure 8: Collective marketing simulated NPV for the poor farmer category

Projection of the likely impact on resource-poor farmers points to net returns in the range of a loss of Kes 660,000 up to a gain of Kes 21 million with the chance of loss at 26% (Figure 8). This range represents projected total returns over a period of 15 years.

Uncertain variables: poor farmers

Clarity on this outcome is influenced by the high information values of five variables, i.e., size of the cultivated farm area, expansion of farming activities due to credit facilities provided by the cooperative and – to a lesser extent – farmers’ cost of transportation, influence of the cooperative over prices and number of poor farmers joining the cooperative (Figure 9).

Figure 9: Uncertain variables limiting the precision of outcomes simulated by the collective marketing model (poor farmer category)

Returns to middle-income farmers

A middle-income farmer adopting the collective marketing intervention is likely to break even or receive gains of up to Kes 3.5 million. The possibility of gain for the middle-income farmer is 99% (Figure 10).

Figure 10: Collective marketing simulated NPV for middle-income farmers

Uncertain variables affecting collective marketing returns to middle-income farmers

High information value variables are those related to production, possibility and level of expansion of production and the size of cultivated farm area (Figure 11). It should be noted, however, that even though these variables affected the NPV, it is unlikely that any of them could undermine the business case for middle-income farmers.

Figure 11: Uncertain variables limiting the precision of outcomes simulated by the collective marketing model (middle-income farmers)

Returns to wealthy farmers

Wealthy farmers could also either break even or receive earnings of up to Kes 6 million over the 15-year simulation period with the chance of gain at 99% (Figure 12). The variables with high information value in the case of returns to wealthy farmers are the cooperatives' influence over prices, cultivated farm area owned by the wealthy farmer, the farmers' discount rate, as well as variables related to production and losses in production quantity (Figure 13).

Figure 12: Collective marketing simulated NPV for wealthy farmer category

Figure 13: Uncertain variables limiting the precision of outcome projections of NPV simulations for wealthy farmer category

Returns to cooperatives

The cooperative formed for collective marketing has a 74% chance of making gains. The confidence interval for returns to the cooperative ranges from a break-even point to a gain of Kes 2.9 billion (Figure 14).

Figure 14: Collective marketing simulated NPV for the cooperative

Variables limiting the certainty of projected returns to the cooperative

The value of information for the cooperative is highest for the risk of political interference (Figure 15). Also affecting the clarity of projected outcomes is the number of members joining the cooperative, the cultivated farm area by wealthy farmers and yields from that area, increased prices from collective action, the risks of glut, the cost of warehousing, the level of pre-harvest losses and the revenue earned as commission from products sold.

Figure 15: Uncertain variables limiting the clarity of NPV outcomes simulated for the cooperative

Conclusion

In the case of creating beneficial market linkages through cooperative farmer groups, the projected returns indicate that it is most likely to be a profitable endeavour for the farmers. The farmers most likely to lose out, however, are the poorer farmers, whose chance of loss stands at 26% as compared to the negligible 1% chance that middle-income and wealthy farmers face. The possibility of unequal distribution of returns is one that the project partners have taken note of and have put in place measures that those at the bottom can get the most out of their participation. For the model to project expected outcomes more precisely, the programme should look into reducing uncertainty about key variables including the cultivated land area, the cooperative's influence over market prices and productivity factors such as size of cultivated land and degree of postharvest losses.

Intervention 3: Promotion of High-Value Trees

Low agricultural productivity, widespread poverty and the risk of drought are key reasons why livelihoods in the region are largely subsistence-based. Agroforestry is a promising strategy for building resilience of the vulnerable population. Trees can bring commercial gain to subsistence farmers who sell surplus fruit, timber and wood fuel. The income earned makes a significant contribution to rural household incomes and food security. Further, trees contribute important ecosystem services, such as regulation of water cycles and soil erosion. DryDev Programme's intervention on high-value trees promoted *Mangifera indica* (mangoes), *Melia volkensii* (timber, wood fuel) and fodder trees from the *Calliandra* family.

Potential benefits from the promotion of high-value trees

The discussion with implementing stakeholders on benefits to be gained from promotion of high-value trees yielded three categories of benefits: economic, environmental and health benefits. Income could be earned from the sale of tree products, specifically fuel, fodder, fruits and timber.

Economic benefits

$$\begin{aligned} &= \text{price per running foot of timber produced per ha} * \text{timber yields} \\ &+ \text{price per kg of fruits} * \text{kg of fruits produced per ha} \\ &+ \text{price per kg of fodder} * \text{kg of fodder produced per ha} \\ &+ \text{price per kg of charcoal} * \text{kg of charcoal produced per hectare} \end{aligned}$$

Before the income to be gained from the trees could be analysed, consideration needed to be given to the dependence of yields on the time it takes a tree to produce fruits. This was expressed as a mathematical function, which was based on fruit yield expectations. For instance, the maximum yield expected from a mango tree in, say, its 20th year could reach between 400-700 mangoes (95-100%). The tree is expected to start bearing fruit between years 4 and 7 and in that year give 5-10% of the total expected yield. The yield variables were:

- Time to first yield estimate (first bearing age)
- Time to second yield estimate.
- Total expected maximum yield
- First yield estimate as a percentage of maximum yield
- Second yield estimate as a percentage of maximum yield

This treatment was only applied to fruits, as timber, charcoal and fodder yields are a little more regular. Estimates were only needed for yield and price factors for fodder. Yields would be reduced by pre-harvest losses caused by biotic stresses, post-harvest losses and the effects of poor quality planting materials (seedlings). Therefore:

$$\begin{aligned} \text{Fruit yields} &= \text{yield per ha} * \text{average size of farms in the area} \\ &* \text{proportion of a farm planted with fruit trees} \\ &* ((1 - \text{losses due to biotic stresses}) * (1 - \text{postharvest losses}) * (1 \\ &- \text{poor quality materials}_{\text{yes/no}} * \text{losses due to poor quality materials})) \end{aligned}$$

Environmentally, there would be benefits obtained from regulation of ecosystem processes. Carbon sequestration, soil conservation, improved soil fertility, improved micro-climate and hydrological effects are all benefits obtained from afforestation. These environmental benefits were calculated as a cumulative total at the end of the simulation period, i.e., 20 years as opposed to economic benefits, which were computed annually.

Environmental benefits

$$\begin{aligned}
 &= (\text{value of reduced soil erosion per hectare} \\
 &+ \text{value of improved microclimate per hectare} \\
 &+ \text{value of increased water services per hectare}) \\
 &* \text{average size of farms in the area} \\
 &* (\text{proportion of a farm planted with fruit trees} \\
 &+ \text{proportion of farm planted with timber trees})
 \end{aligned}$$

The intervention would also have health benefits from increased food production. Improved nutrition would lead to a reduction in health costs.

Health benefits

$$= \text{benefits from increased food production} + \text{reduction in health costs.}$$

The model also took into consideration that farmers would be incorporating trees into existing farm lands, so that crop yields would still be obtained from the area, until resource competition between trees and field crops makes intercropping no longer feasible. The total benefits from intercropping were calculated as:

Benefits from intercropping

$$\begin{aligned}
 &= (\text{change in profits per hectare due to crop production} \\
 &* \text{probability of intercropping}) * \text{total farm size} \\
 &* (\text{proportion of timber} + \text{proportion of fruit trees})
 \end{aligned}$$

There are project level benefits which were too wide in scope to be included in individual benefit streams and instead were added to total benefits to simulate their widespread effect. The project-level benefit in the case of high-value trees was the reduced number of deaths due to reduced malnutrition.

To determine the scale of the project's benefits, total benefits were multiplied by the adoption rate of farmers in the area. The benefits up to this point were benefits per hectare per year. The adoption pattern was represented as depending on the portfolio of communication strategies used for this intervention. As with interventions 1 and 2, communication to farmers was to be done through workshops (*barazas*) and trade fairs with farmer-to-farmer interactions also contributing to adoption rates:

Number of adopters

$$\begin{aligned} &= \text{farmers targeted by trade fairs} * \text{adoption rate through trade fairs} \\ &+ \text{farmers targeted through workshops} \\ &* \text{adoption rate through workshops} \\ &+ \text{farmers targeted through farmer interactions} \\ &* \text{adoption rate through farmer interactions} \end{aligned}$$

It was expected that some farmers would be dissuaded from adopting high-value trees because they were not willing to wait a number of years to benefit from the fruits.

Total adopters

$$\begin{aligned} &= \text{number of adopters} * (1 \\ &- \text{farmers will reject intervention due to time preference}_{yes/no} \\ &* \text{Percentage of farmers that reject intervention}) \end{aligned}$$

The sum total of individual benefits was then multiplied by the number of adopters to get the grand total of benefits from the project.

Sum total of benefits

$$\begin{aligned} &= \text{health benefits} + \text{environmental benefits} + \text{economic benefits} \\ &+ \text{benefits from intercropping} \end{aligned}$$

Farmer benefits

$$\begin{aligned} &= \text{Sum total of benefits} * \text{Number of adopters} \\ &+ \text{Value of reduced number of deaths.} \end{aligned}$$

To capture benefit streams:

Poor farmers' benefits

$$\begin{aligned} &= \text{number of poor farmers} * \text{farmer benefits} \\ &* \text{low income utility multiplier} \end{aligned}$$

Middle income farmers' benefits

$$\begin{aligned} &= \text{number of middle income farmers} * \text{farmer benefits} \\ &* \text{middle income utility multiplier} \end{aligned}$$

Rich farmers' benefits

$$\begin{aligned} &= \text{number of rich farmers} * \text{farmer benefits} \\ &* \text{high income utility multiplier} \end{aligned}$$

Possible costs

Costs were classified based on the stakeholder incurring the cost, in this case, the implementer and the farmer. All costs were estimated per year.

The total cost function was defined as:

$$\text{Total cost} = \text{cost to farmers} + \text{cost to implementer}$$

The costs incurred by farmers were in three categories defined by time period:

1) Costs that arose during establishment of trees and only incurred once:

- Cost of seeds
 - Cost of tubes
- 2) Perennial costs which would be incurred periodically:
- Cost of fertilizers
 - Cost of on-farm labour
 - Cost of extension services
 - Opportunity cost – losses made by farmers who give up farming land for trees.
- 3) Costs that only arise once the products are produced:
- Costs of marketing
 - Costs of storage
 - Costs of transport to and from markets.

These variables added up to give the total variable '*farmers' costs*'.

To capture streams to farmer demographics:

Poor farmers' costs

*= number of poor farmers * farmer costs*
** low income utility multiplier*

Middle income farmers' costs

*= number of middle income farmers * farmer costs*
** middle income utility multiplier*

Rich farmers' costs

*= number of rich farmers * farmer costs*
** high income utility multiplier*

For the implementer who is promoting trees, costs incurred mainly include advertisement, staff costs and cost of value chain development. Costs were disaggregated into cost of advertisement based on the modes of communication, i.e., farmer field days, farmer-to-farmer interaction and *barazas*, and the investment put into each mode. These costs would only be incurred for the duration of the project, so unlike the farmer, whose cost streams were estimated in the medium-term, implementers' costs were only considered up to the last year the project would be in operation.

Cost to implementer

= cost of salaries + cost of value chain development by species
+ cost of training and advertisement
+ cost of Monitoring, Evaluation and Learning.

Cost of training and advertisement

= investment per targeted farmer through barazas
** farmers targeted through barazas*
+ investment per targeted farmer through farmer field schools
** farmers targeted through farmer field schools*

For all annual cost items, subject matter experts were requested to provide the long-term average, as well as a coefficient of variation that expressed what actual annual values were expected.

These estimates were used to generate time series that truly represented the estimated means while varying from year to year as prescribed by the coefficient of variation.

Possible risks

The risks discussed at the workshop fell into two broad categories: risks that could cause the project to fail, and risks that could only affect the performance of the project, so that the benefits of the intervention would be less than expected. Within these two categories the factors were treated as follows:

1. Factors that could cause the project to fail instantly: This ‘killer factor’ category (those that would lead to failure of the project, i.e. project benefits = 0) only included one type of risk:
 - Political instability/conflict
2. Factors that could reduce performance in all years: Risk factors that would steadily reduce the project’s performance so that outcomes, although not completely eliminated, would be underwhelming:
 - Low tree survival
 - Poor value chain development
 - Poor quality products
 - Lack of market incentives

The risks that cause project failure were used to compute the chance that the project would succeed.

$$\text{Project success} = 1 - \text{risk of political instability}$$

This project success factor would take a value of 0 for each year in which the project failed to deliver any benefits, and a value of 1 for all other years.

Risk factors that reduced project performance would not make project benefits fail altogether, but reduce their value. The ‘benefit scaling factor’ was used to determine how far the benefits would fall below expected benefits.

$$\begin{aligned} \text{Benefit scaling factor} &= (1 - \text{risk of poor quality products}) \\ &\quad * (1 - \text{risk of lack of market incentives}) \\ &\quad * (1 - \text{risk of low tree survival}) \\ &\quad * (1 - \text{risk of poor value chain development}) \end{aligned}$$

Model outputs

The returns from the analysis for individuals in each stakeholder wealth class are shown in Table 4.

Table 4: Summary of returns from high-value trees model in tens of thousands

	0%	25%	50%	75%	100%	Mean	Chance of loss
Returns per poor farmer	(64)	(0.4)	36	86	5,30	56	0.25
Returns per middle-income farmer	(1,20)	(16)	44	1,40	11,00	82	0.31
Returns per wealthy farmer	(3,20)	9.6	1,70	4,20	34,00	2,70	0.24

Returns to poor farmers

The farmers classified as poor in the area are likely to receive benefits in the range of a loss of Kes 640,000 up to a gain of Kes 5.3 million with an average of Kes 560,000. The farmers' chance of loss stands at 25%. Note that this range is simulated for a period of 15 years (Figure 16).

Figure 16: High-value trees NPV simulated for poor farmers

Uncertain variables affecting returns to poor farmers

The variables creating the most uncertainty and causing such a large range in expected benefits were the production quantities and price of fodder, as well as the landholding size of these poor farmers. The risks of farmers producing poor quality materials and the risk of inadequate market incentives are also high-value variables (Figure 17).

Figure 17: Uncertain variables which limit the precision of outcomes simulated by the high-value trees model (poor farmer category)

Returns to middle-income farmers

Middle-income farmers adopting the high-value trees are expected to receive net benefits ranging from a loss of Kes 1.2 million to a gain of Kes 11 million over the simulation period of 20 years. The middle number in this distribution falls at a gain of Kes 440,000 and the average at Kes 820,000. The chance of middle-income farmers experiencing a loss is 31% (Figure 18).

Figure 18: High value trees simulated NPV for middle-income farmer

Uncertain variables affecting returns to middle-income farmers

The variables with the greatest influence on this range were the productivity and price variables of fodder, which were positively related to the returns (Figure 19). Also highlighted are risk variables, the risk of producing poor quality products and the risk of inadequate market incentives, both negatively affecting adoption of the intervention and thus returns. Other high information variables are the size of the farm area the middle-income farmers cultivate and the cost incurred by the farmer for storage facilities.

Figure 19: Uncertain variables limiting the precision of simulated NPV outcomes for middle-income farmer category

Returns to wealthy farmers

Wealthy farmers, though few in number, are more likely to be purely commercial farmers and therefore their expected benefit streams are greater than both middle-income and poor farmers. Returns range from a loss of Kes 3.2 million to a gain of Kes 34 million over the simulation period, with a 24% chance of loss. The median number in this range is Kes 1.7 million and the average Kes 2.7 million (Figure 20).

Figure 20 :High value trees NPV simulated for wealthy farmers

Uncertain variables affecting returns to wealthy farmers

High value variables, as seen with poor and middle-income farmers, are the production and cost of fodder, market and product quality risk variables, as well as the size of the cultivated area. For wealthy farmers, high-value variables also included opportunity costs of planting trees, the discount rate and the timber yields (Figure 21).

Figure 21: Uncertain variables limiting the precision of simulated NPV outcomes for wealthy farmers

Conclusion

High value trees were selected for this intervention to promote agroforestry among farmers in the area. The analysis showed that the introduction of such trees, as is to be expected with agricultural interventions, has potential to yield substantial gains for the farmers. However,

results show that there is a chance of loss for farmers, which is somewhere between 20% and 30%, a level that is higher than any of the other simulations.

The model identified the knowledge gaps in the programme which may curtail its success, specifically in terms of lack of incentives for farmers and lack of market for farmers' produce.

Intervention 4: Investment in Water Buffering Structures

In an area characterized by low and irregular rainfall, such as the drylands of sub-Saharan Africa, water is the principal limiting factor of agriculture. The rainfed agricultural systems used dominantly with little to no supplementary irrigation are particularly vulnerable to water shortages. Efforts to increase the resilience of dryland livelihoods therefore require a focus on water management. Consequently, the DryDev Programme aims to promote farm-level and watershed-level water harvesting structures.

Potential benefits and costs from investments in water harvesting

While water harvesting can support crop production, livestock and human consumption, the analysis focused on the use of these techniques for increased crop production.

For the purpose of comparing the profitability of the proposed water buffer structures, the Net Present Value was calculated separately for each type of structure rather than for different farmer groups. NPV is the time-discounted difference between cash inflows (benefits) and cash outflows (costs) of an investment. The model was designed to create a clearer picture on the most efficient way of achieving water security in the area.

Description of the buffering structures

The water buffering structures considered in this intervention will be structures for on-farm water conservation as well as conservation at the watershed level.

On-farm structures

- Zaï pits
- Sunken beds
- Fertility trenches
- Farm ponds
- Drip irrigation kits

Structures at the watershed level

- Sand dams
- Sub-surface dams
- Shallow wells

The cost-benefit valuation was disaggregated by the type of structure to capture structure-specific benefit streams.

To calculate returns, we defined the function *practice_NPV*, to calculate the NPV for each structure based on three categories:

- Benefits from the structure: profits, additional ecosystem services
- Initial costs which occur only once and are applied in year 1: cost of establishment
- Recurring costs which are applied in all years: Maintenance costs, cost of labour

These variables were estimated in terms of added costs, as compared to a situation without water harvesting structures.

These variables were then plugged into the *practice_NPV* function to calculate the NPV for each farmer. Note that the first equation calculated NPV for each structure on a per-hectare basis. To do so, the inputs to the function consisted of specific variables such as benefits per ha, one-time costs and recurring costs.

$$\begin{aligned} \text{NPV per structure per hectare} \\ = \text{Benefit from the structure} - (\text{Initial costs} + \text{recurrent costs}) \end{aligned}$$

Benefits= Additional profit

An example of the expanded function applied to zaï pits is given below:

$$\begin{aligned} \text{Benefits} &= (\text{additional profit per ha} + \text{value of additional ecosystem services zaï pits}) \\ \text{one time costs/ha} &= (\text{additional establishment cost}) \\ \text{Recurring costs/ha} &= (\text{additional zaï maintenance cost} + \text{additional zaï pits labour cost}) \end{aligned}$$

Thus:

$$\text{NPV of zaï pits} = \text{Benefits of zaï pits} - \text{One time costs/ha} - \text{Recurring costs/ha}$$

The second formula used the NPV per structure per hectare to calculate the returns accruing to a single farmer's household by considering the proportion of land for which water from the structure is used:

$$\begin{aligned} \text{NPV per farmer} \\ = \text{NPV per structure per ha} * \text{area cultivated by a farmer} \\ * \text{proportion of cultivated area watered by water structure} \end{aligned}$$

It was clear that in general, the benefit and cost variables were mostly similar for the structures, but with differing values. For the two watershed level structures, the farmers incurred no costs, with initial construction being the responsibility of the implementers in conjunction with government agencies. Going by discussions with partners, they would work with the community to maintain the structures; therefore, maintenance would go to the farmers using the structures either in direct financial capacity or in provision of labour. Because the structures require little maintenance, these costs were unlikely to be high.

There were also some positive externalities that could be reasonably expected to come from implementation of the project. Such general benefits, including reduced dependence on aid and benefits from improved social cohesion were estimated in aggregate for each farmer and added to the total NPV. These variables gave us NPV totals:

$$\begin{aligned} \text{Total NPV for the farmer} \\ = (\text{NPV from zaï pits} * \text{Number of farmers adopting zaï pits}) \\ + (\text{NPV from sunken beds} * \text{Number of farmers adopting sunken beds}) \\ + (\text{NPV from fertility trenches} \\ * \text{Number of farmers adopting fertility trenches}) \\ + (\text{NPV from farm ponds} * \text{Number of farmers adopting farm ponds}) \\ + (\text{NPV from shallow wells} * \text{Number of farmers adopting shallow wells}) \\ + (\text{general benefits} * \text{Number of adopters}) + \text{NPV from sand dams} \\ + \text{NPV from Subsurface dams} \end{aligned}$$

Possible risks

Certain factors posed a risk to the expected returns and should they occur, they would reduce the projected benefits.

The variables identified by the estimating partners as posing a risk to the project were:

- 1) Political interference
- 2) Poor project design and management
- 3) Conflicting approaches among implementing organizations
- 4) Low farmer adoption.

The treatment of risks in the model was done in such a manner that the possibility of occurrence of the risk and the magnitude of the effect on project benefits were multiplied to total up to a specific risk.

Once the risks were quantified, they were multiplied together to give one factor dubbed ‘scaler’ which was applied to reduce project returns.

$$\begin{aligned} \text{Risk of political interference} &= \text{political interference}_{yes/no} * \\ &\text{effect of political interference on project returns} \end{aligned}$$

$$\text{Risk of poor design and management}$$

$$= \text{occurrence of poor design and management}_{yes/no}$$

$$* \text{effect of poor design and management on project returns}$$

$$\text{Risk of conflicting approaches} = \text{conflicting approaches}_{yes/no} *$$

$$\text{effect of conflicting approaches}$$

$$\text{Risk of low adoption} = \text{low adoption}_{yes/no} * \text{effect of low adoption}$$

$$\text{Scaler} = \text{risk of political interference} * \text{risk of conflicting approaches}$$

$$* \text{risk of poor project design and management} * \text{risk of low adoption}$$

Model outputs

Unlike the previous analyses, which looked at the returns from each intervention, the intervention on water buffering structures was structured as a comparative analysis in order to use the model outputs to prioritize the most profitable structures over less profitable ones.

Figure 22: NPV streams from on-farm water buffering structures

Figure 22 shows the benefit streams from on-farm water-buffering structures. We see that farm ponds are most promising with a 90% confidence interval for returns ranging from a loss of Kes 2.6 million on the lower end and a gain of Kes 44 million. Drip irrigation is ranked second with returns between a loss of Kes 3.4 million and gains of Kes 26 million over the 30-year lifespan of the project (90% confidence interval), albeit with the lowest chance of making a profit at nearly 80%. Fertility trenches projected the lowest margins with a 90% confidence interval ranging from a gain of Kes 11,000 to gains of Kes 680,000. With fertility trenches, however, the probability of gains is quite high at 91% (Table 5).

Table 5: Chance of gain from on-farm water buffering structures

On farm water buffering structure	Chance of gain
Zaï pits	95%
Sunken beds	92%
Fertility trench	91%
Farm ponds	99%
Drip irrigation	79%
Shallow wells	79%

Value of information analysis for each water harvesting structure

The value of information analysis performed on each on-farm structure showed that the variables with the highest value of information in all cases were the profit that the farmer could earn per hectare and the contributions of the water structures toward a farm's crop income. The farmer's discount rate also appeared as an important factor for a majority of the results (Figure 23 to Figure 28).

Figure 23: Uncertain variables limiting the precision of NPV outcomes projected for farm ponds

Figure 24: Uncertain variables limiting the precision of NPV outcomes projected for Zai pits

Figure 25: Uncertain variables limiting the precision of outcomes projected for sunken beds

Figure 26: Uncertain variables limiting the precision of NPV outcomes projected for fertility trenches

Figure 27: Uncertain variables limiting the precision of NPV outcomes projected for drip irrigation

Figure 28: Uncertain variables limiting the precisions of outcomes projected by the NPV simulation for shallow wells

Comparative analysis: watershed level structures sand and sub-surface dams

Sand dams and sub-surface dams are communal structures estimated to yield long-term gains or losses running into millions. Sand dams largely promise a higher NPV than sub-surface dams,

with a 90% confidence interval ranging from between gains of about Kes 210,000 to gains of Kes 29 million (Figure 29). Sub-surface dams, while still profitable, appeared less favourable, with returns estimated to fall within the range of Kes -1.8 million to Kes +12 million.

Figure 29: Comparative analysis of watershed level structures

Figure 30: Uncertain variables limiting the precision of NPV outcomes projected for a sand dam

Variables with the highest value of information when it came to NPV of sand and sub-surface dams are largely similar. The income from the dam to households and the farmers' cost of maintenance ranked highest on the list, with the size of land cultivated by the farmers with water from the structures, the ecosystem benefits of the structures and the farmers' discount rates adding further uncertainty to the outcome projections (Figure 30 and Figure 31).

Figure 31: Uncertain variables limiting the precision of NPV outcomes projected for sub-surface dams

Conclusion

The water harvesting structures proposed by DryDev Programme have the potential to significantly improve farmers' productive capacity. The analysis, while able to illustrate a range of returns which the farmers could anticipate, is unable to gain clarity and give a precise answer on how much the intervention could earn. To do so, the analysis recommends that implementers obtain more information on the variables highlighted as being highly uncertain.

Recommendations

The results outlined above were presented to participating SMEs, in this case project partners, during a one-day workshop held at ICRAF Headquarters on 2 October 2015. The ensuing discussion yielded the following comments on the relevance of the model and its results, as well as the overall modelling process:

1. The partners would have liked to see annual or even 5-year trends in results which would have offered greater insight into specific variables than the lumpsum NPV result for a period of 20 years that was used.
2. Partners expressed interest in comparing the actual project outcomes with the model projections as they expect that there would be a few discrepancies between model results and farmers' experiences.
3. Partners also recommended that greater focus be placed on individual variables and their impact pathways.
4. Partners acknowledged the usefulness of including uncertainty in projecting project outcomes, but also raised questions on the rigour of the uncertainties analysed, particularly on whether the analysis accounted for 'Black Swan' situations.

Limitations and the Way Forward

DryDev Programme underwent a transformation in its second year which saw some changes in its work plan. This affected the relevance of the models built as they were based on the previous year's plans. They do, however, offer insight and initiate conversation into the application of fairly new scientific methods in project implementation. The expected value of information, for example, is useful for its role as a guide to identify critical knowledge gaps. There is a possibility that these knowledge gaps, apart from just being monitored, could also be addressed by new interventions in the project.

The method of analysis itself also proved challenging as it depended on the implementer's availability to provide data on a large number of variables. This was a problem as they were often in the field and had little time to spare. This was solved by dividing the work among the implementing agencies so that each could provide data from the specific aspects they were working on.

Overall Conclusion

Implementers of the DryDev Programme sought to make better-informed decisions by conducting a decision analysis on the potential of four interventions within six project sites in Eastern Kenya. This approach is well suited for representing and quantifying the project's impact pathway, including all the activities and risks. It could also constitute a new generic approach to project planning, monitoring and evaluation, and impact assessment.

The cost-benefit modelling approach used was both participatory and probabilistic. Participants were agents from implementing organizations who were asked to identify variables and trained to parameterize the model by giving data estimates in ranges. The use of probabilities allowed the model to incorporate prevailing uncertainties resulting in more realistic projected returns.

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