Agricultural Technology Assessment for Smallholder Farms in Developing Countries: An Analysis using a Farm Simulation Model (FARMSIM)

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Abstract

The rural population in developing countries depends on agriculture. However, in many of these countries, agricultural productivity remains low with episodes of famines in drought-prone areas. One of the options to increase agricultural productivity is through adoption and use of improved agricultural technologies and management systems. Being a relatively high risk business due to factors related to production, marketing and finance, agriculture requires to devise risk mitigating strategies. Several models used to evaluate the adoption of agricultural technologies focus mainly on assessing the ex-post impact of technology without necessarily quantifying the profit and risk associated with the adoption of technologies. This paper introduces a farm simulation model (FARMSIM) that attempts to evaluate the potential economic and nutritional impacts of new agricultural technologies before they are adopted (ex-ante). FARMSIM is a Monte Carlo simulation model that simultaneously evaluates a baseline and an alternative farming technology. In this study, the model is used to analyze the impact of adoption of small scale irrigation technologies and fertilizers on the farm income and nutrition of smallholder farmers in Robit1 kebele, Amhara region of Ethiopia. The farming technologies under study comprise water lifting technologies (pulley and tank, rope and washer pump, gasoline/diesel motor pump and a solar pump) and use of fertilizers. The key output variables (KOVs) are the probability of positive annual net cash income and ending cash reserves, probability of positive net present value and a benefit cost ratio greater than one. For nutrition, the KOVs relate to the probability of consumption exceeding average daily minimum requirements of an adult for calories, protein, fat, calcium, iron, and vitamin A. The application of recommended fertilizers on grain and vegetable crops, alongside the use of irrigation to grow vegetables and fodder using a motor pump had the highest net present value compared to other scenarios. Similar results were observed for the net cash farm income and the ending cash reserves. However, the most feasible and profitable scenario is the one under the pulley system which had the highest benefit cost ratio. Solar pump system had the lowest benefit cost ratio due most likely to high initial investment cost. As for the nutrition, the simulation results show an increase in quantities available to the farm family of all nutrition variables under all alternative scenarios. However, the daily minimum requirements per adult equivalent were met only for calories, proteins, iron and vitamin A but deficiencies were observed for fat and calcium.

Key words: simulation, irrigation, technology, risk, nutrition

1 Robit kebele is one of the intervention sites in Ethiopia under the Feed the Future Innovation Laboratory for Small Scale Irrigation (ILSSI) project funded by the United States Agency for International Development (USAID)
1.0. Introduction

The rural poor in developing countries depends on agriculture and about 70 percent of extreme poverty around the world is found in rural areas (Norton, 2014). For most of the world’s poorest countries, especially those on the African continent, agriculture continues to be the main source of employment and contributes to a large portion of the GDP. However, in many of these countries, agricultural productivity remains low with episodes of famines in drought-prone areas (Qasim, 2012). To understand why people remain poor and hungry it is important to know the factors affecting agricultural productivity which include but are not limited to technologies, resources and institutions that regulate the economy (Norton, 2014).

Adoption of agricultural technologies can play a pivotal role in increasing agricultural productivity and reducing poverty among rural populations. However, adopting and using new agricultural technologies has never been an easy task because of many factors that are involved in the adoption process. Factors that influence the extent of adoption of technology can include, characteristics or attributes of technology; the adopters or clientele, the change agent (extension worker); and the socio-economic, biological, and physical environment in which the technology takes place (Cruz, 1987). Generally, farmers look at some or all of those factors and choose to adopt a technology based on their utility and profit maximization behaviors (Qasim, 2012; Barungi and Maonga, 2011). The assumption is that farmers engage in adoption of new technology only if the benefits or perceived utility of using the new technology outweighs the benefits of the current or old technology.

Several models have been used to measure the adoption of technologies specifically the binary choice models, which do not necessarily quantify the profit and risk associated with production but rather assess the ex-post impact of technology adoption (Diagne et al., 2013; de
Janvry et al., 2011). The key result from these models is the average effect of adoption on outcomes (yields, revenues, profit…) for those who have adopted technologies, also called “the average treatment effect”. However, because of the selection problem, the main challenge is to establish the proper counterfactual group against which to compare adopters especially in the early stage of adoption where we have large numbers of non-adopters (de Janvry et al., 2011). Another concern in impact assessment using this approach stems from the inability to detect statistically significant differences in poverty-related outcome measures and income when agricultural technologies generate only small increments in yields and income. Also, note the difficulty of capturing the spillover effect from adoption, which affects adopters and non-adopters. The main issue with the average treatment is its variation over time because the adopters change how they use the new technology with time as they learn more about it and a number of late adopters join the early adopters group. It is also a challenge to search for a counterfactual since a true counterfactual should not be “contaminated” by adopters. To overcome this issue, other types of approaches built around simulation models such as the computable general equilibrium models (CGE) have been used to measure the adoption of technology. While these are useful models (especially at the macro level), they neither estimate impacts nor capture the risk associated with agricultural production at the farm level.

The method discussed above for evaluating the impact of technology has mainly focused on the ex-post evaluation. The approach this paper will focus on, however, evaluates the potential impacts of new agricultural technologies before adoption takes place (ex-ante evaluation). A farm level simulation model (FARMSIM) is used to carry out this task. In addition to assessing and quantifying the economic profit, the model evaluates the nutritional outcomes for a farm family of adopting new agricultural technologies based on the increased
consumption and sale of production surplus to buy other foods not produced on the farms. All these output variables are projected for five years and presented in terms of probability distributions based on historical yield and price risk. It is recognized that the spillover effects from technology adoption are not captured by a farm level simulation model but can be properly handled by a sector model. Nonetheless, effects related to price elasticities to reflect the changes in revenues and costs from a potential increase in crop production are taken into account by the FARMSIM model. The focus of this paper is to describe the FARMSIM model and evaluates the probable economic and nutritional impacts of adopting agricultural technologies in developing countries using a case study from Robit kebele (village), Amhara region of Ethiopia.

2.0. Literature review

Farmers in developing countries need not only to acquire improved agricultural technologies for crop and animal production but also be protected against undue risk related to agricultural production (Norton, 2014). Adoption of new agricultural technologies leads not only, to increasing productivity and food security, but also enhances agricultural development while reducing poverty. However, risk and uncertainty linked to the process of agricultural production and marketing constitute one of the barriers for farmers to adopt new agricultural technologies.

2.1. Technology adoption and agricultural development

Productivity of smallholder farms in developing countries is known to be constrained by several policy and structural issues that have led to slow increases in crop yields and stagnation (Yengoh et al., 2009; Norton, 2014). The absence of technologies, limited access to or the use of inappropriate technologies have been in part blamed for the lack of increases in productivity and persistent food insecurity in developing countries. Usually it is assumed that with the right technology (seeds, irrigation, fertilizers, technique, tools), the agricultural production will be
increased and food security restored in areas with physical and social limitations to production. However, this has not always been the case. National governments, international agencies and several development organizations have attempted to make agriculture more productive and profitable by introducing agricultural technologies but with modest results (Yengoh et al., 2009). Several factors have contributed to low or lack of adoption of new technologies in developing countries including the limited access to the technologies. Even where these technologies have been adopted the dissemination to a larger segment of the population has failed in some cases.

For instance, conservation technologies have been introduced in places with steep slopes and where erosion was a major limiting factor to production, such as in the Ethiopian highlands (Gebrehaweria et al., 2013). Part of this technology package include the soil and water conservation (SWC) techniques which are widely accepted as a key strategy to improve agricultural productivity by reducing water shortages, effects of droughts, and worsening soil conditions. However, in the rain-fed agro-ecological landscapes of Ethiopia, the low yield (on average about 35% of the potential) is usually not due to the lack of water but rather a result of the inefficient management of water, soils, and crops (Amede 2012). Given the modest impact and outcome of these conservation measures, emphasis of the interventions should not only focus on the engineering and biophysical performance of conservation measures but also on the socioeconomic and livelihood benefits (Zemadim et al. 2011).

Studies from the Ethiopian Highlands show that the adoption of SWC technologies is influenced by a variety of factors, including biophysical characteristics such as topography, slope, soil fertility, rainfall amount, and rainfall variability (Deressa et al. 2009). Experience also shows that even when technologies are appropriate for the biophysical setting, they are not always adopted because farmers consider a variety of factors when making a decision to adopt a
particular intervention (McDonald and Brown 2000; Soule et al. 2000). In addition, studies have found that both farmers’ recognition of the problem (e.g., soil erosion and low agricultural productivity) and awareness of the potential solutions are necessary, but not sufficient conditions for the adoption and continued use of SWC technologies (Merrey and Gebreselassie 2011). Externally driven technical solutions are rarely sustained by farmers unless consideration is given to socioeconomic, cultural and institutional as well as biophysical and technical factors.

2.2. Accounting for risk in agricultural technology adoption

Agriculture is often characterized as a relatively high risk and uncertain enterprise in the economy due to a number of risky factors related to the agricultural business such as production, marketing and finance (Hardaker, et al., 2004; Qasim, 2012). Some of the risk and uncertainty components surrounding the production and marketing processes are related to unpredictable weather variation (drought, frost, flood, and wind storm), input quality, pest and disease attacks, price fluctuations, new technology failure, and changes in government policies. These factors are some of the main causes of farm production and income fluctuations both at the micro and macro-economic levels. Financial risk is more related to the failure to meet liabilities with the cash generated through farm revenues due to a mismatch between cash inflows and outflows, the level of debt, and other sources of financial resources. The risk becomes more important when the household heavily depends on loans for farm investments. The combined effect of production, marketing, institutional and personal risk, called business risk, is the cumulative effect of all the uncertainty surrounding the profitability of the firm (Hardaker et al., 2004). There is a need to explicitly take into account risk in agriculture because farmers cannot control all of the factors related to agricultural production and marketing. Due to unpredictable weather and under harsh climatic and agro-ecological conditions, crop production failure can result in
food insecurity and famines such as those that have happened to the highlands of Ethiopia over the last 40 years (Di Falco and Chavas, 2009). For instance, with recurring drought and a high risk of harvest failure, ex-ante farm production decisions based on crop and varietal choices are part of risk management strategies. In the same way, adopting water and land conservation along with the irrigation technologies can help cope with drought risk.

In this paper, risk is taken into account to study the economic and nutrition impacts of adopting small-scale irrigation (SSI) technologies in Robit kebele. Farm modeling using a Monte Carlo simulation model is one of many approaches that can help in analysing risk and studying the economic feasibility of adopting SSI technologies on a farm (Richardson et al., 2007).

3.0. Data and study area

The case study of Robit kebele used both primary and secondary data for FARMSIM input farming information. The primary data source consisted of a household and community survey conducted in 2014 by the ILRI-LIVES project (see Gebremedhin et al., 2015). The primary data were supplemented by secondary data that included expert opinion, research articles, and reports from government and non-government agencies. The information from the survey and other sources were summarized according to the FARMSIM model data input sheet which requires information on crops, livestock, assets, liabilities and fixed and variable costs for a representative farm. The input data for a representative farm in Robit was drawn from a sample of 24 households.

Robit kebele (village) is located in Bahir Dar Zuria district (woreda), West Gojam zone in Amhara region of Ethiopia approximately 20 Kms from Bahir Dar town (fig. 1). The Robit

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For more information on the survey, see this link: https://lives-ethiopia.org/2014/06/06/baseline-surveys/
The village area has an average elevation of 1848 masl. According to the 2007 Ethiopia Census results, a total of 8900 people are living in the kebele (Population Census Commission).

A mixed crop/livestock production is the predominant farming system in the area where the main crops grown include maize, finger millet, teff, rice, and chickpeas. Crops are grown using both rain and irrigation water. Two major cropping seasons are identified in Ethiopia: **Kiremt** and **Bega**. **Kiremt** is the main rainy season (June-September) during which major field crops (mainly grains) are grown and harvested in **Meher** season. Irrigated crops such as tomatoes, grass peas, chickpeas, cabbage and onions are grown during the **Bega** season (dry from October to January).
The main source of irrigation water is from shallow wells. Most of the households keep cattle, small ruminants, poultry and bees (apiculture). Cattle are basically raised to meet draught power requirements while milk, meat, manure, dung cake, breeding replacement stock are income sources. The majority of the milk produced is retained for home consumption. However, some milk is processed into butter for sale and family consumption. Donkeys are as well kept, mainly for transportation purposes. Even though the study is on the village of Robit, only a representative farm will be simulated in the model to identify the impact of new agricultural farming technologies on farm profit and nutrition (see characteristics of a farm in Appendix A).

4.0. Methods

4.1 FARMSIM model description

The farm simulation model “FARMSIM” is a Monte Carlo simulation model that simultaneously evaluates a baseline and alternative technologies for a farm. The model is programmed in Microsoft ® Excel and utilizes the Simetar© add-in to estimate parameters for price and yield distributions, simulate random variables, estimate probability distributions for key output variables (KOVs) and rank technologies (Richardson et al., 2006)³. FARMSIM is programmed to recursively simulate a five year planning horizon for a diversified crop and livestock farm and repeats the five-year planning horizon for 500 iterations⁴. A new sample of random values is drawn to simulate each iteration. After simulation, the resulting 500 values for each of the KOVs define the empirical probability distributions that compare the base and alternative

³ FARMSIM is a micro-computer, Excel/Simetar driven, enhanced version of FLIPSIM designed to simulate smallholder farms in developing countries. FLIPSIM has been used extensively for policy analysis and technology assessment for farms in the United States (Richardson and Nixon, 1985).

⁴ Extensive testing with the Latin Hypercube sampling procedure in Simetar has shown that a sample size of 500 iterations is more than adequate to estimate a probability distribution for KOVs in a business model with more than 100 random variables.
farming technologies or interventions. By comparing the probability distributions for the base and alternative technologies, decision makers can quantitatively analyze the probable consequences of introducing alternative technologies.

FARMSIM is programmed to simulate up to 15 crops as well as cattle, dairy, sheep, goats, chickens, and swine annually for five years. The farm family is modeled as the first claimant for crop and livestock production with deficit food production met through food purchases using net cash income from selling surplus crops and livestock production. Standard accounting procedures are used to calculate: receipts, expenses, net cash income, and annual cash flows. The KOVs for the model can include all endogenous variables in the model but most attention is focused on the following KOVs: annual net cash income, annual ending cash reserves, net present value, benefit-cost ratio (BCR), internal rate of return (IRR), and annual family nutrient consumption of protein, calories, fat, calcium, iron, and vitamin A (fig. 2).

4.2 Monte Carlo simulation for technology and risk analysis

Simulation has become an important tool for risk analysis and a decision aid tool to manage risk for farmers and policy makers. Part of the process to determine the level of risk and its mitigation is the simulation of the stochastic variables that bear most of the risk: prices and yields. In stochastic simulation, random or stochastic components are incorporated in simulation models to calculate the key output variables (KOVs), by repeatedly sampling from the probability distributions for multiple random variables to capture the uncertainty in the real system. Since many input variables are stochastically dependent, this requires estimating and simulating the joint distribution, which in return provides the stochastic component for the simulation model used to generate the probability distributions of the key output variables (KOVs).
Figure 2. FARMSIM model diagram (adapted from Nyangito et al., 1996, p. 165)
A procedure, based on the multivariate empirical (MVE) probability distribution, was developed to simulate stochastic variable in farm-level models used in policy and strategic planning analyses (Richardson, Klose and Gray, 2000). The procedure consists of a semi-parametric Monte Carlo simulation technique, which incorporates intra- and intertemporal correlation and allows the researcher to control the heteroscedasticity of the random variables over time.

Stochastic annual output prices and yields for crops and livestock are simulated using multivariate empirical (MVE) probability distributions estimated from historical data. The baseline and alternative technology scenarios are simulated by FARMSIM using the same equations so the only difference in the economic and family nutrition outcomes are due to the technology differences. The random crop yields are simulated using the same stochastic uniform standard deviates to insure that the weather risk for a crop under the base and alternative technology scenarios are identical. The same stochastic prices for crops are used for both scenarios, unless the alternative scenarios call for a different marketing program, which shifts the price distribution to a different level. Since the base and alternative models use identical equations, the decision maker can be assured that the differences in the KOVs are due to the differences in the two farming systems and their assumed yield distributions.

4.3 FARMSIM economic and nutrition equations

The FARMSIM model consists of accounting and nutrition equations that describe annual production, marketing, financial management, household consumption and nutrition. Four major components of the model are presented: crops, livestock, financial and nutrition (see details of the FARMSIM model equations in Appendix B).

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5 In this study, stochastic annual crop yields were simulated from an MVE probability distributions estimated using 32 years of crop yields generated by APEX (Agricultural Policy / Environmental eXtender) (Williams et al., 1998). A GRKS probability distribution is used where no historical data is available. Selected SSI technologies are simulated by APEX using the same historical weather data and plant growth parameters consistent with the technologies under study.
**Crop Model.** The farm family can grow/consume up to 15 different crops/food stuffs. The crops in the model are dependent upon the local crops produced and consumed in the local area. The order of the crops is specified by the analyst so the model is applicable across countries and farming systems. Crop production equals the product of stochastic yield and hectares planted (Eq. 3). Family consumption is calculated as the maximum of average annual kilograms consumed or a fraction of total production. If surplus production exists it can be paid to employees and landowners, where applicable. After satisfying family food needs, employee compensation and rent requirements, the remaining crop production is sold.

Cash receipts for crops equals quantity sold times the stochastic market price (Eq. 8). Market prices are simulated using either a GRKS probability distributions elicited through expert opinion in the absence of historical data or a multivariate empirical (MVE) probability distribution where historical prices are available. As an input, the GRKS distribution (developed by Gray-Richardson-Klose and Schuman) uses three parameters (minimum, a mid-point, and a maximum) and then assigns a piecewise normal distribution such that 50% of the density is below the mid-point and 50% is above the mid-point.

Cash costs of production for crops are calculated as the product of hectares planted and the sum of per hectare costs for seed, fertilizer, chemicals, weeding, irrigation, land preparation, harvesting, and other cash costs (Eq. 9). There are no econometric equations in the crop model because all simulated variables can be calculated as simple identities and standard accounting practices.

**Livestock Model.** The livestock component of FARMSIM simulates annual production and herd dynamics for cattle, oxen, chickens, sheep, goats, and swine. Since the cattle sector is the most complex it is described here in detail (Eq. 13-27). The other livestock sectors are
modeled similarly. The number of cows on January 1 less cows consumed, cows die, and cows culled, plus raised replacements, and purchased cows equals the number of cows on December 31. Cows consumed and cows that die are calculated based on relevant fractions for consumption and death and the number of cows on January 1. Cows culled and purchased are endogenous variables calculated annually to maintain the cow herd at the user’s pre-determined number of cows for each year.

The number of calves born each year is the product of the number of mature cows on January 1 and the stochastic annual calving rate. Half the calves are assumed to be heifers and half are bulls. The fraction of calves consumed by the family, die or are sold, decrease the number born to arrive at the number of yearling heifers and bulls on December 31. Different death rate, consumption, and sold fractions can be used for bull and heifer calves. The model can either sell bull calves or retain them to raise oxen on the farm.

The number of 12 month old heifers on December 31 equals the number of 12-24 month old heifers January 1 of the subsequent year. The ending year number of 12-24 month old heifers is calculated based on the fraction of two year-old heifers that are consumed by the family, die or are sold during the year. The same process is used to dynamically simulate the 25-36 months old replacement heifers. It is assumed replacement heifers are bred to calve at 40-48 months when they enter the cow herd.

The dynamics of the oxen herd is similar to the cow herd. The number of oxen on January 1 is reduced for the fractions consumed, die or are culled (sold). The number of oxen raised or purchased to maintain the desired herd size is added to the net January 1 herd size to calculate the inventory of oxen on December 31.
Milk production is calculated by multiplying stochastic milk per cow times the number of lactating cows (Eq. 28). The number of lactating cows equals the number of cows that calved each year. Milk production per cow is a stochastic variable simulated using an expert opinion parameterized GRKS distribution that is augmented by fractional adjustments for forage production. Low (high) forage production reduces (increases) the stochastic milk per cow value in the current year. Low forage production not only affects milk production in the current year but also reduces the stochastic fertility rate. Thus a drought causes decreased milk production for two years as fewer lactating cows are available in the second year.

Milk consumption by the family is a fraction of total milk production. A fraction of the milk can be made into butter which can be consumed by the family or sold. Milk not consumed or made into butter is sold. Receipts for cattle are calculated using the stochastic prices for the respective age categories and the number of head sold plus receipts for milk, butter, hides, and manure (Eq. 29). The receipts for hides come from multiplying a price for hides by the number of cattle and oxen that die or are consumed. Manure receipts are calculated as the product of manure prices and the sum of manure produced by the cows, calves, replacements, and oxen, if the manure is not used on the farm.

Cash costs for the cattle herd are calculated by multiplying the annual cash costs for cows, calves, two year olds, three year olds, and oxen by the number of head on December 31 (Eq. 10). The annual cash costs are inflated each year by assumed rates of inflation. As indicated above, the livestock model has similar detail for simulating the herd dynamics, receipts, and costs for sheep, goats, and swine. For chickens the production, consumption, and sale of eggs is added to the flock dynamics which are similar to the other livestock species.
**Nutrition Model.** The total kilograms of each raised crop consumed by the family plus the kilograms of purchased foodstuffs are multiplied by their respective nutrient scores to calculate total calories, protein, fat, calcium, iron and vitamin A from the food stocks (e.g. of proteins in Eq. 41). Similar calculations are made to simulate the nutrients derived from consuming cattle, oxen, milk, butter, chickens, eggs, mutton, lamb, nannies, kids, and pig meat. Total nutrients consumed by the family from all sources, including donated food, are summed across plant and animal food stocks and compared with minimum daily recommended amounts for adults based on the FAO requirements standards (FAO, 2001; FAO, 2010).

**Financial Model.** The financial model consists of three pro forma financial tables: income statement, cash flow, and balance sheet (Eq. 32-40). The income statement shows the source of annual receipts from crops, cattle, chickens, sheep, goats, and swine. Annual cash expenses from these same profit centers plus fixed costs and interest costs are summarized in the income statement. Annual net cash income equals total cash receipts minus total cash expenses.

The cash flow statement calculates cash inflows, cash outflows, and ending cash reserves. Cash inflows equal the sum of beginning cash, net cash income, off farm income, and interest earned for cash reserves (Eq. 35-40). Cash outflows equal the sum of cash purchases of food, school expenses, family living expenses, income taxes, principal payments, and repayment of cash flow deficits in the previous year. Ending cash reserves on December 31 equals total cash inflows minus total cash outflows.

The balance sheet summarizes assets and liabilities for the farm (Eq. 42-46). Annual assets equal the value of land, livestock, machinery, and positive cash reserves. Annual liabilities equal remaining debt for initial loans and new debts, and negative cash reserves. Net worth equals assets minus liabilities.
Net present value for the farm family equals the present value of annual family withdrawals plus the value of crops and livestock consumed, plus the present value of ending net worth, minus the beginning net worth (Eq. 49). A 10% discount rate is used to calculate net present value.

Two NPV-related metrics commonly used to assess the economic feasibility and profitability of project or enterprise are as well included in FARMSIM: internal rate of return (IRR) and benefit-cost ratio (BCR). The IRR is defined as the discount rate that need to be applied to generate a NPV value of zero. Benefit-cost ratio (B/C) is the ratio of the present value of the benefits to the present value of the costs. If the ratio is greater than one, the business or project is profitable. This is an equivalent condition to the NPV criteria where if the discounted present value of the benefits exceeds the discounted present value of the costs then the project is worthwhile.

5.0. Technology scenarios analysis: case study of Robit

5.1. Crop production scenarios

Data input into FARMSIM is entered in parallel. For each input variable the user must provide information for the current (baseline) and alternative farming system (scenario) (see flowchart in Appendix C). The model is designed so the user can enter complete data sets for the baseline and up to 21 alternative scenarios. Due to the importance of irrigation in crop and livestock production and recurrent drought episodes observed in Ethiopia, small scale irrigation technologies will be discussed using a case study of Robit kebele (village) in the Amhara region of Ethiopia. Small scale irrigation technologies enable smallholder farmers to have dry season crops that provide improved nutrition and generate income with less risk, provided that there is a sustainable source of water for the land area to be irrigated. The scenario analysis consists of the evaluation of water lifting technologies and fertilizer applications. Given that
most of water used for irrigation in Amhara is groundwater from wells, four different water lifting technologies ranging from pulley and tank, to rope and washer pump, to motor and solar pumps will be evaluated for their capacity and affordability (Appendices D1 and D2).

Three major cereal crops consistent with the current cropping systems in Robit are considered. They comprise maize, teff and millet grown during the wet season. In addition to cereal crops, chickpeas, potato, cabbage, tomato, fodder and napier grass are studied in the model (Appendix E1). Assuming no need for supplemental irrigation for the cereal crops, chickpeas and potato, the main difference in yield between the baseline and alternative scenarios in terms of technology input would mainly come from fertilizer application.

Different sources of literature including a recent household survey carried out in Robit by the ILRI-LIVES project indicate that a relatively adequate amount of fertilizer (DAP and Urea), close to the recommended rates, is used in household farms in Robit for maize and millet (Minot and Sawyer, 2013; Rashid et al., 2013). Increased levels of fertilizers were used for teff in the alternative scenario. As for chickpeas and potato, additional fertilizers were applied in alternative scenarios for potato since chickpeas did not show any stress for phosphorus and has the capability of fixing nitrogen (Appendix E 2). The survey information shows that most of the households used stored seeds from the previous harvest for the following planting season and that the use of chemicals was limited. It was also noted that the level of farm labor hiring for agricultural production was low since family members performed most of the agricultural tasks. It is worth mentioning that, the use of actual crops to feed animals is not common as most of the animal feed comes from crop residues.

The irrigated crops are grown during the dry season and consist mainly of tomato and cabbage in the vegetable category and fodder (vetch/oats) and napier grass in the animal feed category. Note
however that a portion of fodder and napier grass production was simulated as a market commodity (cash crop) while the remainder was used to feed animals. While the required fertilizer rates for tomato were applied for the alternative scenario (Urea: 200 Kgs/ha and DAP: 50 Kgs/ha), household data from the ILRI-LIVES survey showed only limited application of the current fertilizer rates (baseline scenario) (Appendix E2). Only Urea was applied by a few households at a rate of 150 Kgs/ha (average of all 10 households was 56 Kgs/ha) while no farmer applied DAP. In the case of cabbage, the baseline and alternative scenarios differed as to the quantities of applied irrigation water and subsequent water stress levels, which were at 50% for the baseline and zero percent for the alternative scenarios. However, similar amounts of fertilizer rates were applied for both scenarios. For fodder and napier grass, additional amounts of fertilizer to the current levels were applied. Details for crop yields and associated input costs for the baseline and alternative scenarios are in Appendix E3. Five scenarios under study are summarized below:

- Baseline: current fertilizer + current tillage + no irrigation
- Alt.1 (Pulley): irrigate vegetables, fodder and napier with pulley & tank + recommended fertilizer
- Alt.2 (Rope-Hand): irrigate vegetables, fodder and napier with rope & washer pump + recommended fertilizer
- Alt.3 (Motor Pump): irrigate vegetables, fodder and napier with motor pump + recommended fertilizer
- Alt.4 (Solar Pump): irrigate vegetables, fodder and napier with solar pump + recommended fertilizer

5.2. Livestock production technologies

Improving animal feed resources can have a tremendous impact on both household income and nutrition through the production, consumption and sale of live animals and animal products. In
this study small scale irrigation (SSI) technologies along with fertilizer application were used to grow and improve yields of fodder and napier grass with a purpose of feeding animals and generating income. Supplementing animal feeding with fodder and napier grass is expected to increase milk production and animal live weight which in turn will improve the family nutrition through milk, butter and meat consumption and generates income through the sale of live animals and animal products.

Livestock production technologies were aligned with crop production and water lifting irrigation technologies (Appendix F). In the baseline scenario fodder crops (oats & vetch) and napier grass are grown on limited land with minimal irrigation and fertilizer applications. However, in the alternative scenarios, more land is allocated to fodder and napier especially during the dry season due to irrigation. Additional land area covered by irrigation for fodder and napier grass varies according to the water lifting technology pumping capacity. Higher fertilizer rates are also applied in the alternative scenarios compared to the baseline. A portion of the total production of fodder and napier grass is fed to cows and bulls to increase the production of milk and meat while the remainder is sold for income generation.

Preliminary results on the calculations of meat and milk production from a single cut of fodder (vetch & oats mix) and napier grass were produced by researchers at the International Livestock Research Institute (ILRI) (ILSSI mid-term report, October 2016)⁶. Assuming all forage is used for production and none for maintenance purposes and considering local cattle breeds feeding with fodder (oats & vetch) and napier grass, there is on average a live weight gain of around 52.4 Kgs and an improved milk yield of 312 liters per year per cow. We assumed also an adoption rate of 60% for the livestock, doubling the 30% rate of adoption.

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⁶ Find the report at: [http://ilssi.tamu.edu/media/1389/final-ilssi-mtr-6-dec-16-3.pdf](http://ilssi.tamu.edu/media/1389/final-ilssi-mtr-6-dec-16-3.pdf)
indicated by the LIVES household survey. The number of cattle is held constant for the 5 year planning horizon. Following are the baseline and alternative livestock technology scenarios:

- Baseline: No irrigation + current animal feeding (no supplemental feed)
- Alt. Scenario 1: Irrigation of fodder & napier w/pulley + supplemental fodder
- Alt. Scenario 2: Irrigation of fodder & napier w/ R &W pump + supplemental fodder
- Alt. Scenario 3: Irrigation of fodder & napier w/motor pump + supplemental fodder
- Alt. Scenario 4: Irrigation of fodder & napier w/solar pump + supplemental fodder

5.3. Technology scenarios ranking

In addition to evaluating the profitability of SSI technologies, a utility-based approach is used to rank the different alternative scenarios for their preferences to the decision maker. A range of methods can be used to rank scenarios that include means, standard deviation, and coefficient of variation. While some of these approaches include risk, they are not robust enough to always unambiguously, rank scenarios without taking into account the risk preference of the decision maker. Therefore, incorporating utility-based ranking methods to compare alternative farming scenarios is a better approach to help the decision maker select among the scenarios.

About four utility-based ranking functions are included in Simetar and can be used by the FARMSIM model to rank alternative farming scenarios. They comprise the Stochastic Dominance with Respect to a Function (SDRF), Certainty Equivalent (CE), Stochastic Efficiency with Respect to a Function (SERF) and Risk Premiums (RP). In this study, SERF was used to rank the risky alternatives given its many advantages over the others. Hardaker, Richardson, Lien and Schuman (2004) merged the use of CE and Meyer’s range of risk aversion coefficients to create the stochastic efficiency with respect to a function (SERF) method for ranking risky alternatives. SERF assumes a utility function with a risk aversion range of $U(r_1(z),
r_2(z)) and evaluates the CEs over a range of risk aversion coefficients (RAC) between a LRAC (lower RAC) and an URAC (upper RAC). The range can go from an LRAC = 0 (risk neutral) to URAC = 1/wealth (normal risk aversion). In ranking the risky alternatives, the SERF approach compares the CE of all risky alternative scenarios for all RACs over the range and chooses the scenario with the highest CE at the decision maker’s RAC as the most preferred (identifying the efficient set) and summarizes the CE results in a chart. Any key output variable (NPV, NCFI, EC…) distribution can be selected to rank alternative farming systems (irrigation technologies).

5.4. **Micro and macro level assumptions**

First, to show the full potential of adopting new technologies, we assumed that the alternative farming technologies simulated in this study on crop production and use of water lifting technologies are adopted at 100 percent. The concern for farmers to acquire the irrigation tools such as pumps due to the high capital cost was partially addressed by making available loans to purchase the irrigation pumps through microfinance institutions with the help of the Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI) /International Water Research Institute (IWMI). As for livestock production technologies related to feeding animals with fodder and napier grass supplement, we assumed a 60% adoption rate, doubling 30 percent original adoption rate found from the household data survey.

Second, since the farmer’s profit mainly depends on the amount of crop and livestock (including livestock products) sold at the markets, accessibility to markets by the farmers is of paramount importance. The markets were assumed to be accessible and function competitively with no distortion where the supply and demand determine the market prices. Accessibility to markets and competitive market prices depend mainly on the existence of road and market infrastructure.

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in the Bahir Dar Zuria district where survey results show that farmers reported on average 1.4 km (0.9 miles) distance to market. Last, in the five-year economic forecast, market selling price in each of the five years was assumed to equal the average selling price of year 1 for each crop sold.

6.0. Simulation results and discussion

A baseline and four alternative scenarios are simulated and forecasted for a five year period in FARMSIM to evaluate agricultural and livestock technologies in Robit kebele. Due to limited space, only the year five simulation results are presented in this section using several graphical and analytical tools to rank the risky alternatives scenarios in comparison to the baseline. Cumulative distribution function (CDF), probability density function (PDF) and StopLight charts, all available in SIMETAR program, are presented in the results to compare the scenarios in terms of their financial and nutrition variables.

Net present value (NPV)

NPV is an indicator that assesses the feasibility and profitability of an investment or project over a certain period of time. Overall, the NPV simulation results as illustrated by the cumulative distribution function (CDF) indicate that it is worth investing in irrigation and fertilizer application (see graphs in Appendix G1). The application of recommended fertilizers on grain and vegetable crops, together with the irrigation of vegetables and fodder crops using a pulley/tank, rope-and-washer, motor, or solar pumps (Alts. 1, 2, 3, and 4, respectively) showed outstanding performance, in that their CDF values lie to the right of the baseline scenario for all 500 draws of the simulation model. The motor pump scenario (Alt. 3) has the highest NPV value (at each risk level) compared to the pulley/tank, rope-and-washer and solar pump scenarios. All four of the alternative scenarios show higher NPV values than the baseline scenario.
**Net cash farm income (NCFI)**

Annual NFCI measures the amount of profit generated by the farm for the baseline and alternative scenarios. The simulation results indicate that the motor pump scenario (Alt. 3) generated higher NCFI than the baseline and other alternative scenarios. The pulley/tank, rope-and-washer pump and solar pump scenarios (Alts. 1, 2 and 4, respectively) generated the second highest levels of NCFI (see CDF graph in Appendix G3).

The StopLight chart for NCFI in fifth year of the 5-year planning horizon shows that, for a representative farm or household in the baseline scenario, there is a 54% probability that NCFI will be less than 19,000 ETB and a 13% probability that NCFI will exceed 30,000 ETB (fig. 3). In contrast, for the motor pump scenario (Alt. 3), there is a 61% chance that annual NCFI will exceed 30,000 ETB, 33% probability that NCFI will fall between 19,000 and 38,000 ETB, and only 6% that the NCFI will be less than 19,000 ETB. The second best scenarios that generated higher profit are pulley/tank, rope-and-washer pump and solar pump scenarios (Alts. 1, 2 and 4, respectively), which recorded on average a 35% probability that NCFI will exceed 30,000 ETB, 40% chance that the NCFI will fall between 19,000 ETB and 30,000 ETB, and a 24% probability that annual NCFI will fall below 19,000 ETB. All the alternative scenarios performed better and generated higher profits than the baseline scenario. It is worth mentioning that higher NPV and profit values from alternative scenarios are associated with the expansion of irrigated land and the increase in production and sale of crops and livestock products at the market.
Figure 3. StopLight chart for per-family NCFI in Robit kebele

Legend
Baseline: No irrigation;
Alt.1--P: Pulley and Tank;
Alt.2--R&W: Rope & Washer pump;
Alt.3--MP: Motor pump
Alt.4--SP: Solar pump

Benefit-cost ratio (BCR) and internal rate of return (IRR)

Although an alternative farming technology such as a motor pump may generate the highest income and profit amount, it may not have the highest economic return on investment. For this reason, two commonly used and NPV-related metrics, the BCR and IRR, were simulated to evaluate the economic feasibility of the different alternative technologies.

Any alternative scenario in the study that shows a positive average value of the BCR (>1) and an average value of IRR greater than the discount rate (>0.10) would be deemed feasible and profitable as compared to the baseline scenario (both metrics are based on the present value of
the difference). The average values in table 1 and figure 4 show that all alternative scenarios have positive BCR values with the pulley leading the alternative scenarios with a higher BCR value (5.5) than the rest of the irrigation scenarios. Notice that the solar pump has the lowest BCR value (1.9) among all other alternative scenarios. This outcome may be explained by the level of investment costs (irrigation tool) which is higher for the solar pump and lower for the pulley in comparison to the irrigation benefits. Although the motor pump has the highest net profit, its BCR value is ranked second alongside the rope and washer pump scenario. A similar outcome is observed for the IRR with the pulley showing a higher return to investment (1.6) compared to other alternative scenarios (Alt. 2 & 3 average IRR of 1.1). The solar pump has the lowest return to investment (0.4) compared to other irrigation tool under study.

**Table 1. Economic impacts of SSI technologies in Robit kebele**

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Alt.1--Pulley</th>
<th>Alt.2--R&amp;W</th>
<th>Alt.3--MP</th>
<th>Alt.4--SP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Averages values in Birr /family in year 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net present value</td>
<td>129,925</td>
<td>176,956</td>
<td>177,752</td>
<td>209,895</td>
<td>180,138</td>
</tr>
<tr>
<td>Avg. net profit</td>
<td>19,216</td>
<td>26,559</td>
<td>26,750</td>
<td>34,195</td>
<td>27,321</td>
</tr>
<tr>
<td>% change profit: Alt./Baseline</td>
<td>38%</td>
<td>39%</td>
<td>78%</td>
<td>42%</td>
<td></td>
</tr>
<tr>
<td>Benefit-Cost Ratio: Alt/Baseline</td>
<td>5.5</td>
<td>3.9</td>
<td>3.9</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Internal Rate of Return: Alt/Baseline</td>
<td>1.6</td>
<td>1.1</td>
<td>1.1</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

Note:
Baseline: No or minimal irrigation;
Alt.1--Pulley: Pulley-tank used in optimally irrigated systems
Alt.2--R&W-P: Rope & Washer pump used in optimally irrigated systems
Alt.3--MP: Motor pump used in optimally irrigated systems
Alt.4--Solar-P: Solar pump used in optimally irrigated systems

For economic variables: numbers in green show increase while those in red show decrease
Baseline and alternative scenarios ranking

NPV and NCFI simulation results above indicate the predominance of the motor pump scenario compared to the other three alternative scenarios (pulley, rope and washer pump and the solar pump) and the baseline. To complete the scenarios ranking, the stochastic efficiency with respect to a function (SERF), is used to compare and rank the different scenarios based on the decision maker (DM) utility for income and risk. In addition to comparing income averages values, this approach considers four levels of risk aversion for a typical decision maker: risk neutral, normal risk aversion, moderately risk averse and extremely risk averse. The scenarios are ranked based on their certainty equivalence (CE) value or profit as well as their level of risk aversion. Similar results as observed above show consistently the dominance of the motor pump scenario in its ability to generate more profit compared to other scenarios at all level of risk aversion (fig. 5). The next most preferred scenarios are the pulley/tank, rope & washer pump, and solar pump.
scenarios (Alts. 1, 2 and 4). Notice in figure 5 the CEs or profit for all scenarios functions decrease as the level of risk aversion increases, which indicates the decision maker’s willingness to take less profit to shield against high risk.

Figure 5. SERF ranking of alternative farming systems in Robit kebele

The SERF option in Simetar produces as well a risk premium (RP) chart. The chart shows the perceived premium that each risky scenario provides relative to the baseline scenario at different risk aversion levels (Appendix H). A positive RP over the range of risk aversion levels for an alternative scenario means its preference over the baseline while a negative RP would mean the preference of the baseline scenario over the alternative scenario. The motor pump scenario (Alt. 3) has the highest risk premium compared to other alternative scenarios and the baseline scenario. Notice also that all other alternative scenarios have a positive PR compared to the baseline.
**Nutrition simulation results**

In general, the adoption and proper use of agricultural technologies contribute to an increase in the quantity and variety of crops produced. The implications for family nutrition vary according to the types of crops grown and consumed. Also surplus crops can be sold and resulting revenues be used to buy food items needed to complement nutrition requirements. The LIVES household baseline survey information shows that individual households in Robit kebele, did not purchase large quantities of food or receive any food aid as a supplement to their production.

Nutrition simulation results indicate that the quantities of crops and livestock products consumed by families in both the baseline and alternative scenarios met minimum daily requirements per AE for calories, proteins, iron and vitamin A but were insufficient for calcium and fat (table 2) (see information on minimum requirements in FAO, 2001 and FAO, 2008). Note that the farm level nutrition simulation study in FARMSIM reflects strictly the availability and accessibility by the farm family of the six food nutrients: calories, proteins, fat, calcium, iron and vitamin A.

**Table 2. Nutritional outcome of SSI technologies in Robit kebele**

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Alt.1--Pulley</th>
<th>Alt.2--R&amp;W</th>
<th>Alt.3--MP</th>
<th>Alt.4--SP</th>
<th>Min. required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Averages daily nutrients in year 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (calories/AE)</td>
<td>2,776</td>
<td>3,682</td>
<td>3,683</td>
<td>3,721</td>
<td>3,686</td>
<td>1,750</td>
</tr>
<tr>
<td>Proteins (grs/AE)</td>
<td>67.6</td>
<td>91.0</td>
<td>91.1</td>
<td>92.9</td>
<td>91.2</td>
<td>41</td>
</tr>
<tr>
<td>Fat (grs/AE)</td>
<td>28.7</td>
<td>37.5</td>
<td>37.5</td>
<td>37.9</td>
<td>37.5</td>
<td>39</td>
</tr>
<tr>
<td>Calcium (grs/AE)</td>
<td>0.19</td>
<td>0.35</td>
<td>0.35</td>
<td>0.38</td>
<td>0.35</td>
<td>1</td>
</tr>
<tr>
<td>Iron (grs/AE)</td>
<td>0.019</td>
<td>0.027</td>
<td>0.027</td>
<td>0.028</td>
<td>0.027</td>
<td>0.009</td>
</tr>
<tr>
<td>Vitamin A (grs/AE)</td>
<td>0.0026</td>
<td>0.0061</td>
<td>0.0061</td>
<td>0.0065</td>
<td>0.0061</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

**Note:**
For nutrition variables: numbers in red show quantities of nutrients intake < minimum required
AE = Adult Equivalent

The calorific intake simulation results for a typical household in Robit kebele indicate an average daily calories intake of 2,770 and 3,680 calories, respectively for the baseline and alternative scenarios which is significantly higher than the daily minimum requirement of 1,750 calories per
adult equivalent (AE) (table 2). This may be due to large land allocation to the grain crops and the use of fertilizer that contributed to an increase in grain production and mitigated any deficiency in energy and calories for both the baseline and alternative scenarios. Moreover, survey information shows that, on average, 68% of all grains produced by households in Robit kebele are consumed at home.

The protein intake simulation results in both the baseline and alternative scenarios (67 and 93 grams/AE respectively) show that on average households meet and exceed the daily minimum requirement for proteins intake of 41 gr/AE. There is a significant improvement in protein intake for the alternative scenarios compared to the baseline scenario. However, household surveys showed that the majority of the proteins consumed in Robit kebele were obtained from crops rather than animal products.

Simulation results for fat show a deficit in fat intake for both the baseline and alternative scenarios. Although there is an improvement of fat intake between the baseline and the alternative scenarios, their respective averages, 28 and 37 grams, are below the average of 39 grams daily minimum fat requirement for an adult.

A similar issue of deficit was observed for calcium intake quantities. The simulation results for calcium show large deficits in calcium intake in both the baseline and alternative scenarios. The average calcium intake per AE is around 0.19 and 0.35 grams, respectively, for the baseline and four alternative scenarios, falling short of the daily minimum requirements of 1 gram per AE. Note however the significant improvement of calcium intake from the baseline to the alternative scenarios which almost doubled.

As for iron, simulation results indicate that households in Robit kebele consume more than the required minimum levels of iron. The average iron intake per AE of all scenarios, estimated at
0.023 grams (or 23 mg), was more than two times greater than the daily minimum requirement of 0.009 grams (or 9 mg) per AE. There was also a significant improvement between the baseline and the alternative scenarios in iron intake, which averaged 0.19 and 0.27 grams respectively. Finally, the simulation results for vitamin A intake indicate adequate to surplus vitamin A intake levels in both the baseline and alternative scenarios. The average levels of vitamin A intake for the baseline (0.0026 grams) and the alternative scenarios (0.0064 grams) are 4 to 10 times higher than the daily minimum requirement for an adult equivalent (0.0006 grams). Detailed nutrition simulation results and graphs are in Appendix J.

Simulated levels of nutrition variables (calories, proteins, fat, calcium, iron and vitamin A) available to farm families increased substantially in the alternative scenarios because of production increases in the alternative scenarios due to farming technology (fertilizer and irrigation) and crop diversification. The increase in yields allowed farm families to produce sufficient food for consumption, which provided different nutrients needed for human consumption except for fat and calcium. Also the representative farm grew seven different crops ranging from grains (maize, teff and millet), vegetables (tomatoes and cabbage), root crops (potatoes), pulse (chickpeas), and animal feed (fodder and napier). Although the animal feed crops are not directly used for human consumption they are fed to livestock for milk, butter and meat production used in human consumption. With improvement in livestock production, the deficiencies in fat and calcium can be filled by the consumption of milk, eggs, cheese, butter and meat. Hence, food supplements either through purchase or farming to increase the intake for fat and calcium will be needed to meet the nutritional requirements and the well-being of the families in Robit kebele.
7.0. Conclusions and recommendations

The purpose of this study was to evaluate the impacts of adopting agricultural technologies (increased fertilizers and irrigation) on household nutrition and farm profitability in Robit kebele, Amhara region of Ethiopia. A baseline scenario with current fertilizer application rates and no or minimal irrigation was compared to four alternative scenarios where recommended fertilizers rates and irrigation were applied to crops. In the alternative scenarios, increased fertilizer rates were applied only to grow teff and potatoes since millet and maize showed adequate amounts of fertilizer by household surveys. Tomato, cabbage, fodder and napier grass received increased levels of fertilizers as well and were irrigated during the dry season using four alternative water-lifting technologies that include pulley/tank, rope and washer, motor and solar pumps. The preferred scenario, consisting of the use of recommended fertilizers in combination with motor-pump irrigation of tomato, cabbage, fodder, and napier grass, generated the highest income and profits for the farm. The next-best performing scenarios used pulley/tank, rope-and-washer or solar pump for irrigation in combination with recommended. It is worth noting that the solar pump had the same outcome in terms of profit as the pulley/tank and the rope and washer pump despite the relatively high investment costs of the solar pump. The baseline scenario was the least preferred of all five scenarios analyzed. However, cost-benefit analysis indicated the pulley system to have the highest return on investment.

The use of improved farming systems based on fertilizer and irrigation technologies had a positive impact on livestock production which increased the meat and milk output and improved the consumption of animal products at the household level. Nutrition levels improved significantly in the four alternative scenarios compared to the baseline scenario as a result of the improvements in crop yields due to the application of fertilizer and irrigation technologies.
Expanding the types of crops irrigated in the dry season to increase family nutrition and net cash income is recommended, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits.

Further studies would focus on how the profits could increase if households shared a single pump for irrigation in the dry season, and on how diversifying the crops consumed (whether through the farming of additional crops or purchase) could impact nutrition.
References


Richardson, J. W. (2006). Simulation for applied risk management. Unnumbered staff report, Department of Agricultural Economics, Agricultural and Food Policy Center, Texas A&M University, College Station, Texas.


APPENDICES

Appendix A: farm and village characteristics

Table 6. Smallholder farm characteristics in Robit kebele

<table>
<thead>
<tr>
<th>*Average farm size (ha):</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- cropland</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>- pastureland</td>
<td>0.26</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Current crops (ha/kebele):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Maize</td>
<td>728</td>
</tr>
<tr>
<td>- Millet</td>
<td>708</td>
</tr>
<tr>
<td>- Teff</td>
<td>266</td>
</tr>
<tr>
<td>- Tomato</td>
<td>102</td>
</tr>
<tr>
<td>- Fodder (oats &amp; vetch)</td>
<td>86</td>
</tr>
<tr>
<td>- Onion</td>
<td>43</td>
</tr>
<tr>
<td>- Green Pepper</td>
<td>40</td>
</tr>
<tr>
<td>- Chickpeas</td>
<td>57</td>
</tr>
<tr>
<td>- Potato</td>
<td>23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Livestock (# heads/kebele):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cows</td>
<td>2805</td>
</tr>
<tr>
<td>- Heifers</td>
<td>1652</td>
</tr>
<tr>
<td>- Bulls</td>
<td>827</td>
</tr>
<tr>
<td>- Calves</td>
<td>330</td>
</tr>
<tr>
<td>- Oxen</td>
<td>2974</td>
</tr>
<tr>
<td>- Goats</td>
<td>397</td>
</tr>
<tr>
<td>- Sheep</td>
<td>6196</td>
</tr>
<tr>
<td>- Chicken</td>
<td>21649</td>
</tr>
<tr>
<td>- Pigs</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Assets (Birr/ household):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Value tools &amp; Building</td>
<td>7444</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>*Liabilities/household</th>
<th>Amount (Birr)</th>
<th>Interest (%)</th>
<th>Terms (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Land loan</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>- Technology loan</td>
<td>1750</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>- Miscellaneous loan</td>
<td>2625</td>
<td>20</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix B: FARMSIM model equations

The equations in FARMSIM are summarized as follows:

Stochastic annual yields are simulated as:

\[ \bar{Y}_{it} = \bar{Y}_{it} \times (1 + MVEMP(S_y,F(X),CUSD_{yt})) \]

\( \bar{Y}_{it} \) is mean yield of crop \( i \) in year \( t \),

\( MVEMP \) is the multivariate empirical function,

\( S_y \) is the matrix of fractional deviations from mean yields for all crops,

\( F(X) \) is the cumulative distribution 0 to 1 for the \( S_y \) matrix, and

\( CUSD_y \) is a vector of correlated uniform standard deviates for crop yields in year \( t \).

All equations are repeated for both the base and alternative scenarios. In the case of crop yield each scenario has a different \( S_y \) matrix and \( \bar{Y}_{it} \) vector to match the technology, but use the same \( CUSD_y \) vector so both scenarios experience the same weather shocks. The model allows the farm to have up to 15 crops which can be made up of field crops and kitchen garden crops.

Stochastic annual crop prices are simulated as:

\[ \bar{P}_{it} = \bar{P}_{it} \times (1 + MVEMP(S_p,F(X),CUSD_{pt})) \]

\( \bar{P}_{it} \) is mean price for crop \( i \) in year \( t \),

\( MVEMP \) is the multivariate empirical function,

\( S_p \) is the matrix of fractional deviates from mean prices for all crops,

\( F(X) \) is the cumulative distribution 0 to 1 for the \( S_p \) matrix, and

\( CUSD_{pt} \) is a vector of correlated uniform standard deviates for crop prices in year \( t \).

The mean price vectors can differ between the base and alternative technology scenarios if one scenario assumes a different marketing option or a different quality of the crop. The multivariate
empirical methodology used by FARMSIM is described in detail in Richardson, Klose, and Gray (2000).

Production of each crop $i$ is simulated as:

(3) \[ \bar{Prod}_{it} = Acres_{it} \times \bar{Yield}_{it} \]

$Acres_{it}$ is the land area devoted to the crop and can be acres, hectares, or any other local name for land area. The model simulates the production identity using stochastic yield so production for each crop is stochastic given weather shocks to yields.

The quantity of the crop which can be sold is the residual after subtracting out the quantity consumed by the family and livestock.

*Family consumption and livestock feed requirements are identities that are simulated as:*

(4) \[ Family\ Consumption_{it} = QF_{i} \times No.\ Adult\ Equivalent \]

$QF_{i}$ is the minimum quantity of crop $i$ consumed per adult equivalent per year and $No.\ Adult\ Equivalent$ is the number of adult equivalents in the farm family.

(5) \[ Livestock\ Feed_{it} = \sum_{j} (QL_{ij} \times No.\ Head_{jt}) \]

$QL_{ij}$ is the quantity of crop $i$ fed to livestock type $j$ each year and $No.\ Head_{jt}$ is the number of adult equivalent animals of type $j$ where $j$ is the type of livestock: cattle, swine, chickens, sheep, and goats.

*Quantity of each crop sold is simulated in two steps:*

(6) \[ \bar{ProdR1}_{it} = \bar{Prod}_{it} - Family\ Consumption_{it} \]

(7) \[ \bar{ProdSold}_{it} = MAX \left(0, (\bar{ProdR1}_{it} - Livestock\ Feed_{it})\right) \]

Cash receipts for crops are simulated as:

(8) \[ \bar{CR}_{it} = \bar{Prod\ Sold}_{it} \times \bar{PriceC}_{it} \]

*Variable costs for each crop $i$ are simulated as:
\[ VC_{it} = \sum_j \left( Acres_{it} \times V_{ijt} \times (1 + Infl\ Rate_{jt}) \right) \]

\( VC_{ijt} \) is total variable costs for each crop \( i \) in year \( t \),

\( V_{ij} \) is the variable cash cost per acre (land unit) for input \( j \) applied to crop \( i \), where \( j \) represents seed, fertilizer, herbicides, irrigation fuel, labor, marketing, etc., and

\( Infl\ Rate_{jt} \) is the annual inflation rate in the price per unit of input \( j \) for year \( t \).

Variable costs for each livestock type are simulated as:

\[ VL_{jt} = \sum_j \left( No.\ Head_{jt} \times V_{ij} \times (1 + Infl\ Rate_{jt}) \right) \]

\( VL_{jt} \) is the variable cost for each type of livestock \( j \), and

\( V_{ij} \) is the variable cash cost per adult animal of type \( j \).

Fixed cash costs for the farm are simulated by inflating the farm’s initial values and summing over the multiple categories of costs.

\[ FC_t = \sum_k \left( FC_{kt-1} \times (1 + Infl\ Rate_{kt}) \right) + Interest\ Payments\ for\ Land\ Loan + Interest\ Payments\ for\ Machinery\ and\ Livestock\ Loans \]

\( FC_{kt} \) is fixed cost for \( k \) categories which include expenses for: land leasing, property taxes, insurance, interest for loans, etc.

Total cash costs for the farm family are:

\[ TC_t = (\sum_i VC_{it} + \sum_j VL_{jt} + FC_t) \times (1 + Interest\ Rate) \]

The interest rate in equation (12) is the rate charged for the operating loan if one is in place.

Livestock production is simulated similarly for cattle, swine, sheep, goats, and chickens with of course exceptions for milk production and the biological progression from infants to adults, i.e., calves to cows. Given that cattle is the most complicated livestock sector, its equations are presented in detail.
The user must specify the number of cattle in four age groups (i.e., cows, 3 year-old heifers, 2 year-old heifers, and 1 year-old heifers). Calving fraction is a stochastic variable simulated using an empirical probability distribution.

\[ \tilde{C}_P_t = \tilde{C}_P_t * (1 + EMP(S, F(x), USD_t)) \]

\( \tilde{C}_P_t \) is the average calving fraction such as 0.50 meaning that on average half of the adult cows have a calf.

Death rates for cattle are simulated for each age cohort and for bulls as a multivariate empirical distribution:

\[ \tilde{D}R_{nt} = \tilde{D}R_{nt} * (1 + MVEMP(S, F(x), CUSD_t)) \]

\( \tilde{D}R_{nt} \) is a vector of average death rates for cows, heifers 3, 2, and 1 years of age, calves, and bulls.

Milk per cow is a stochastic variable simulated using an empirical probability distribution:

\[ \tilde{M}/C_t = \tilde{M}/C_t * (1 + EMP(S, F(x), USD)) \]

\( \tilde{M}/C_t \) is average milk per cow.

Prices for cattle and milk as well as all livestock types are simulated as a multivariate empirical probability distribution for each technology scenario.

\[ \tilde{P}rice_{jt} = \tilde{P}rice_{jt} * (1 + MVEMP(S, F(x), CUSD_t)) \]

\( \tilde{P}rice_{jt} \) is the average price vector for all livestock types by age cohort and product such as milk and eggs.

Number of calves born is simulated as:

\[ \tilde{C}alves_t = Cows_t * \tilde{C}P_t \]

Number of calves that die during the year is simulated as:

\[ \tilde{C}alves\ Die_t = \tilde{C}alves_t * \tilde{D}R\ calves_t \]
Number of heifer calves enter 1 year heifer herd:

(19)  \( Heifers_{1t} = (\hat{Calves}_{t} - \hat{Calves \ Die}_{t}) \times 0.5 \)

Number of 1 year-old heifers enter 2 years-old herd.

(20)  \( \tilde{Heifers}_{2t} = \tilde{Heifers}_{1t-1} \times (1 - \tilde{DR \ Heifers}_{1t}) \times (1 - \tilde{DR \ Heifers}_{2t}) \)

Number of 2 years-old heifers enter 3 years-old herd.

(21)  \( \tilde{Heifers}_{3t} = \tilde{Heifers}_{2t-1} \times (1 - \tilde{DR \ Heifers}_{2t}) \times (1 - \tilde{DR \ Heifers}_{3t}) \)

Number of cows culled is simulated as:

(22)  \( \tilde{Cows \ Culled}_{t} = \tilde{Cows}_{t-1} \times (1 - \text{Cow Cull Fraction}) \)

Number of adult cows that calve during the year is simulated as:

(23)  \( \tilde{Cows}_{t} = (\tilde{Cows}_{t-1} + \tilde{Heifers}_{3t-1} - \tilde{Cows \ Culled}_{t}) \times (1 - \tilde{DR \ Cows}_{t}) \)

Number of bulls die is simulated as:

(24)  \( \tilde{Bulls \ Die}_{t} = \text{No. Bulls}_{t} \times \tilde{DR \ Bulls}_{t} \)

Number of bulls culled is simulated as:

(25)  \( \tilde{Bulls \ Culled}_{t} = \text{No. Bulls}_{t} \times \text{Bull Cull Fraction} \)

Number of bulls to purchase is simulated as the difference between January 1 number of bulls and the number that die and are culled during the year:

(26)  \( \text{Bulls Buy}_{t} = \text{No. Bulls}_{t} - \tilde{Bulls \ Die}_{t} - \tilde{Bulls \ Culled}_{t} \)

No. Bulls\(_t\) is the number of herd sires at the start of the year.

It is assumed that the number of bulls remains constant over the planning horizon so the number of bulls at year end is:

(27)  \( \text{No. Bulls}_{Dec \ 31,t} = \text{No. Bulls}_{Jan \ 1,t} - \text{Bulls Die}_{t} - \text{Bulls Culled}_{t} + \text{Bulls Buy}_{t} \)

Milk production is dependent on the number of cows that calved and milk per cow or:

(28)  \( \tilde{Milk}_{t} = \tilde{Cows}_{t} \times \tilde{M}/\tilde{C}_{t} \times \tilde{CP}_{t} \)
Cash receipts for cattle are calculated as:

\[ \tilde{CR} \text{ Cattle}_t = (\tilde{P}\text{Cows}_t * \tilde{\text{Cows Culled}}_t) + [\tilde{\text{Price Calves}}_t \times (\text{Calves}_t - \text{Calves Die}_t) \times 0.5] + [\text{Price Milk}_t \times \text{Milk}_t \times (1 - \text{Fraction Consumed}_t)] + (\text{Bulls Culled}_t \times \text{Price Bulls}_t) \]

Variable costs for cattle are calculated as:

\[ \tilde{VC} \text{ Cattle}_t = \tilde{Cows}_t \times \tilde{VC} \text{ Cattle}_{t-1} \times (1 + \text{Infl Rate}_t) + (\text{Bulls Buy}_t \times \text{Price Culled Bulls}_t) \]

This equation is an expansion on the formula used for livestock and was presented earlier as equation 10. Similar detailed equations are in place for each livestock type.

Total cash receipts for livestock on the farm are simulated by summing equations similar to equation 29 across all livestock types or:

\[ \tilde{LR}_t = \tilde{CR} \text{ Cattle}_t + \tilde{CR} \text{ Swine}_t + \tilde{CR} \text{ Sheep}_t + \tilde{CR} \text{ Goats}_t + \tilde{CR} \text{ Chickens}_t \]

Total cash receipts from the sale of crops and livestock are simulated as:

\[ \tilde{TR}_t = \sum \tilde{CR}_{it} + \tilde{LR}_t \]

Total cash expenses for the farm family are the sum of variable costs for crops and livestock plus total fixed costs or:

\[ \tilde{TC}_t = \sum \tilde{VC}_{it} + FC_t + \tilde{VC} \text{ Cattle}_t + \tilde{VC} \text{ Swine}_t + \tilde{VC} \text{ Sheep}_t + \tilde{VC} \text{ Goats}_t + \tilde{VC} \text{ Chickens}_t \]

Net cash farm income for the farm family is a KOV for comparing the base and alternative technology scenarios and is simulated as:

\[ NCFI_t = \tilde{TR}_t - \tilde{TC}_t \]
The cash flow for the family is a KOV for determining how an alternative technology scenario compares to the base scenario. Ending cash on December 31\textsuperscript{st} is the objective for simulating the farm family’s cash flow. Cash inflows are simulated as:

\begin{equation}
\tilde{Cash\text{ Inflow}}_t = Beginning\text{ Cash}_{Jan\, 1, t} + \tilde{\text{NCFI}}_t + \tilde{\text{Interest Earned}}_t
\end{equation}

Beginning Cash Jan 1 for \( t = 1 \) is given by the user; in subsequent years it is calculated as:

\begin{equation}
\text{Beginning Cash}_t = \text{MAX} (0, \text{Ending Cash}_{t-1}) \quad \text{for years } t = 2, 3, 4, \text{ and } 5
\end{equation}

\begin{equation}
\text{Interest Earned}_t = \text{Beginning Cash}_{Jan\, 1, t} * \text{Interest Rate}_t
\end{equation}

Cash outflows include principle payments, taxes, and expenses for food purchased and other family living expenses or:

\begin{equation}
\tilde{Cash\text{ Outflow}}_t = \text{Principle Payments}_t + \text{Income Taxes}_t + \text{School Expenses}_t + \\
\tilde{\text{Food Purchased}}_t + \text{Family Living Expenses}_t
\end{equation}

\begin{equation}
\tilde{\text{Food Purchased}}_t = \sum_i (\text{Price } C_{it} * \text{Deficit Food Purchased for Crop}_{it}) + \\
\sum_j (\text{Price } L_{jt} * \text{Deficit Food Purchased for Livestock Type}_{jt})
\end{equation}

If there is insufficient cash to cover all purchases of deficit food supplies, the model uses all available cash to purchase what food it can.

Ending cash for the farm family is:

\begin{equation}
\text{Ending Cash}_t = \text{Cash Inflow}_t - \text{Cash Outflow}_t
\end{equation}

Nutrition calculations for the farm family extend FARMSIM beyond traditional farm budget and whole farm simulation models. The nutritional values for all crops and livestock products (meat, milk, and eggs) consumed by the family are simulated using FAO’s nutrient values for each crop and livestock product (UN-FAO, 2011), based on their average content of protein, calories, fat, iron, calcium and vitamin A. The formula to simulate protein intake for the farm family is:

\begin{equation}
\bar{\text{Protein}}_t = [\sum_i (\text{Family Consumption}_{it} + \text{Purchased Crop}_{it}) *
\end{equation}
Equation 41 is repeated for each of the remaining nutrient categories of: calories, fat, iron, calcium and vitamin A.

FARMSIM simulates the variables to construct a balance sheet for the farm family.

Assets include cash on hand, land, machinery, and livestock.

\[
\text{Assets}_t = \text{MAX} (0, \text{Ending Cash}_t) + \text{Land Value}_t + \text{Machinery Value}_t + \text{Livestock Value}_t
\]

\[
\text{Land Value}_t = \text{Land Value}_{t-1} \times (1 + \text{Infl Rate}_t)
\]

\[
\text{Machinery Value}_t = \text{Machinery Value}_{t-1} \times (1 + \text{Infl Rate}_t)
\]

\[
\text{Livestock Value}_t = \sum_j (\text{LPrice}_{jt} \times \text{No. Head}_{jt})
\]

\[
\text{Liabilities}_t = \text{Land Debt}_t + \text{Machinery Debt}_t + \text{Livestock Debt}_t + \\
\text{MIN} [0, (\text{Ending Cash}_t \times -1.0)]
\]

Debt and principal payments for the different assets are calculated in separate amortization tables to get annual interest and principal payments and remaining debt on December 31.

Net worth is calculated as:

\[
\text{Net Worth}_t = \text{Assets}_t - \text{Liabilities}_t
\]

Present value of ending net worth is used as a KOV:

\[
\tilde{PVENW} = \text{Net Worth}_5 \times [1 / (1 + DR)^5]
\]

\[DR\ is\ the\ discount\ rate\ to\ convert\ future\ values\ to\ present\ year\ values.\]

Net present value is simulated as:

\[
\tilde{NPV} = -\text{Beginning Net Worth}_{t=0} + [\sum_t \text{Family Living Expenses}_t + \text{Value Farm Products Consumed}_t] \times (1 / (1 + DR)^t) - \tilde{PVENW}
\]
(50) Value Farm Products Consumedₜ = \sum_i (Price C_{i1} \times Quantity Crop i Consumedₜ) + 
\sum_j (PriceL_{j1} \times Quantity Livestock Type j Consumedₜ)

Probability of positive net cash farm income is calculated for each year t over the 500 iterations (s) as:

(51) P(NCFIₜ) = \sum_s (1 if NCFIₜs > 0, 0 else) / 500

Probability of a cash flow deficit is a counter variable summed over the 500 stochastic iterations and is calculated for each year. A separate probability is calculated for each year over the 500 iterations (s) as:

(52) P(CFDₜ) = \sum_s (1 if Ending Cashₜs < 0, 0 else) / 500

Probability of economic success is the probability that NPV is greater than zero. If NPV is positive then the farm family’s internal rate of return exceeds the discount rate (DR). The probability is the number of times NPV is positive over the 500 iterations (s) or:

(53) P(ESₜ) = \sum_s (1 if NPVₜ > 0, 0 else) / 500

Probability that the farm family increased its real net worth is the number of times that PVENW exceeds beginning net worth over the 500 iterations (s) or:

(54) P(IRNW) = \sum_s (1 if PVENWₜ > Beg Net Worth, 0 else) / 500

Probability that the farm family’s nutritional intake exceeds the FAO recommended daily requirements is calculated annually over the 500 iterations (s) for each of the six nutrient categories. The formula for each nutrient is the same as the equation for protein.

(55) P(Proteinₜ) = \sum_s (1 if Proteinₜs / 365 > Daily Minimum Reg, 0 else) / 500
Appendix C: FARMSIM Flowchart (excel worksheet organization)

Abbreviations and meaning of different worksheets in FARMSIM:

PRCBASE: price worksheet in baseline scenario
CropBASE: crop worksheet in baseline scenario
LVSKBASE: livestock worksheet in baseline scenario
NUTBASE: nutrition worksheet in baseline scenario
TABLEBASE: table worksheet in baseline scenario

Note: same meaning of the above worksheets applies to the alternative scenarios (CropALT…)

KOV: key output variable
SIMOUT: simulation output
Appendix D1. Water lifting technologies: description and assumptions

To evaluate the benefits and costs for alternative irrigation technologies (pulley vs. rope and washer, motor, and solar pumps) this analysis explicitly considers the costs of the different technologies and the associated amount of land that can be irrigated without water stress. The assessment is based on costs (operating and capital) and capacity of the water lifting technology (pumping rate) to irrigate available land for a given crop’s water needs. The following assumptions are considered for the analysis:

1) Number of active family members (adults) who will carry out the irrigation: 2

2) Number of hours per irrigation day: 1.5

3) Number of irrigation days per season, assuming the farmer irrigates every other day for three and a half months (January-mid April): 65

4) Total number of hours of irrigation per season: 1.5*65 = 97.5 hours/season

5) Pumping rates (liter/min) for the different water lifting technologies are:
   - Pulley & tank: 15 liters/min
   - Rope and washer operated by hand: 15 liters/min
   - Motor pump: 170 liters/min
   - Solar pump: 16 liters/min

The pumping or discharge rates numbers were obtained from field data gathering during the period of March to June 2015 by IWMI on behalf of the ILSSI project.

Based on SWAT model simulation results, it was determined that enough ground water was available to satisfy irrigation needs for all four alternative scenarios. The irrigator’s equation (see Martin, 2011) is used to estimate the total amount of water that can be delivered for each water lifting technology.
Irrigator’s equation: \( Q \times T = d \times A \)

- **Q**: flow or pumping rate (liters/min)
- **T**: time (min) for irrigation
- **d**: depth of irrigation water applied (mm)
- **A**: area covered (m\(^2\) or ha)

Knowing the total amount of water (mm) required to irrigate a crop for the entire dry season and the total amount of water delivered by each water lifting technology per hectare (based on pumping rate and irrigation hours), we computed the fraction of water supply provided by each technology. Given the total irrigable land available for a crop (e.g. tomato) and its water requirements, we use the fraction of water supply by each technology to compute the fraction of available cropland that can be irrigated based on optimal water required to grow tomato for each water lifting technology.

For instance, due to a high pumping rate, a motor pump would in most cases supply more than enough water to irrigate all available cropland. On the other hand, a rope and washer pump operated by hand, a pulley system or a solar pump, assuming the same number of irrigation hours, do not provide sufficient water to irrigate all of the available cropland. A different fraction of the total irrigable land is covered with each irrigation technology (table 5) which reduces the total quantity of tomatoes produced and consequently the farm revenue. Taking into account the initial investment and operating costs for motor and solar systems in the economic analysis, the use of a pulley/tank or a rope and washer pump could be the preferred options for an average farmer to be able to supply enough water to crops during the dry season and make the investment in irrigation worthwhile.
### Appendix D2. Water lifting technology (WLT) characteristics, Robit kebele

<table>
<thead>
<tr>
<th>Types of WLT</th>
<th>Operated by</th>
<th>Flow rate (l/min)</th>
<th>Cost WLT (Birr)</th>
<th>Additional Irrigable Land covered (ha)</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulley/tank</td>
<td>Hand</td>
<td>15</td>
<td>1310</td>
<td>411</td>
<td>labor</td>
</tr>
<tr>
<td>Rope &amp; washer pump</td>
<td>Hand</td>
<td>15</td>
<td>3700</td>
<td>411</td>
<td>breakdowns</td>
</tr>
<tr>
<td>Motor pump</td>
<td>Fuel</td>
<td>170</td>
<td>8500</td>
<td>787</td>
<td>maintenance</td>
</tr>
<tr>
<td>Solar pump</td>
<td>Solar</td>
<td>16</td>
<td>16000</td>
<td>438</td>
<td>capital costs</td>
</tr>
</tbody>
</table>

**Note:** we did not include the cost of digging wells in final estimation given that field data collected by IWMI in 2015 on behalf of ILSSI project shows that several households had a well.
**Appendix E1.** Crop mix and land allocation (ha) scenarios for Robit kebele

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Millet</th>
<th>Teff</th>
<th>Maize</th>
<th>Chickpeas</th>
<th>Potato</th>
<th>Irrigated(^a) Cabbage</th>
<th>Irrigated Tomato</th>
<th>Irrigated Fodder</th>
<th>Irrigated Napier</th>
<th>Total (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wet season</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>708.0</td>
<td>266.0</td>
<td>728.0</td>
<td>57.0</td>
<td>24.0</td>
<td>126.0</td>
<td>102.0</td>
<td>43.0</td>
<td>43.0</td>
<td>2,097.0</td>
</tr>
<tr>
<td>Alt.1 Pulley/tank</td>
<td>708.0</td>
<td>266.0</td>
<td>728.0</td>
<td>110.0</td>
<td>50.0</td>
<td>228.0</td>
<td>204.0</td>
<td>145.0</td>
<td>63.0</td>
<td>2,502.0</td>
</tr>
<tr>
<td>Alt. 2 Rope &amp; Washer Pump</td>
<td>708.0</td>
<td>266.0</td>
<td>728.0</td>
<td>110.0</td>
<td>50.0</td>
<td>231.0</td>
<td>207.0</td>
<td>148.0</td>
<td>63.0</td>
<td>2,511.0</td>
</tr>
<tr>
<td>Alt. 3 Motor Pump</td>
<td>708.0</td>
<td>266.0</td>
<td>728.0</td>
<td>110.0</td>
<td>50.0</td>
<td>356.0</td>
<td>332.0</td>
<td>273.0</td>
<td>103.0</td>
<td>2,926.0</td>
</tr>
<tr>
<td>Alt. 4 Solar Pump</td>
<td>708.0</td>
<td>266.0</td>
<td>728.0</td>
<td>110.0</td>
<td>50.0</td>
<td>240.0</td>
<td>216.0</td>
<td>157.0</td>
<td>63.0</td>
<td>2,538.0</td>
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<tr>
<td><strong>Dry season</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: \(^a\) = total potential irrigable land in Robit is 787 ha (source: SWAT\(^8\) simulation results)

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\(^8\) SWAT (Soil and Water Assessment Tool) model results (p.9) at: [http://ilssi.tamu.edu/media/1333/final-bdz-robit-ex-ante-analysis-of-ssi-scenarios.pdf](http://ilssi.tamu.edu/media/1333/final-bdz-robit-ex-ante-analysis-of-ssi-scenarios.pdf)
### Appendix E2. Current and recommended annual application rates of urea and DAP, Robit

<table>
<thead>
<tr>
<th>Crops</th>
<th>Urea (Kgs/ha)</th>
<th>DAP (Kgs/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>Recommended</td>
</tr>
<tr>
<td>Teff</td>
<td>36</td>
<td>100</td>
</tr>
<tr>
<td>Maize</td>
<td>83</td>
<td>100</td>
</tr>
<tr>
<td>Millet</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Tomato</td>
<td>56</td>
<td>200</td>
</tr>
<tr>
<td>Cabbage</td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>Chickpeas</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Potato</td>
<td>13.3</td>
<td>100</td>
</tr>
<tr>
<td>Fodder (oats &amp; vetch)</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Napier grass</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

### Appendix E3. Mean crop yields (Kg/ha) and input costs (Birr/ha) for baseline and alternative scenarios in Robit

<table>
<thead>
<tr>
<th>Crops</th>
<th>Baseline scenario</th>
<th>Alternative scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teff</td>
<td>838</td>
<td>1614</td>
</tr>
<tr>
<td>Maize</td>
<td>2127</td>
<td>4284</td>
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<tr>
<td>Millet</td>
<td>1640</td>
<td>3110</td>
</tr>
<tr>
<td>Tomato</td>
<td>14293</td>
<td>783</td>
</tr>
<tr>
<td>Cabbage</td>
<td>11376</td>
<td>110</td>
</tr>
<tr>
<td>Chickpeas</td>
<td>1274</td>
<td>358</td>
</tr>
<tr>
<td>Potato</td>
<td>3770</td>
<td>0</td>
</tr>
<tr>
<td>Fodder (oats &amp; vetch)</td>
<td>1398</td>
<td>0</td>
</tr>
<tr>
<td>Napier grass</td>
<td>10936</td>
<td>926</td>
</tr>
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</table>
Appendix F. Input variables and livestock technology scenarios in Robit kebele

<table>
<thead>
<tr>
<th></th>
<th>Baseline scen.</th>
<th>Alt. scen. 1</th>
<th>Alt. scen. 2</th>
<th>Alt. scen. 3</th>
<th>Alt. scen. 4</th>
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<tbody>
<tr>
<td>Cows</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Native</td>
<td>2640</td>
<td>2640</td>
<td>2640</td>
<td>2640</td>
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<tr>
<td></td>
<td>Cross-breds</td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>165</td>
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<tr>
<td>Milk per cow</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Literers/cow/year</td>
<td>185</td>
<td>312</td>
<td>312</td>
<td>312</td>
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<tr>
<td>Live Weight gain (Kgs)</td>
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<td>52.4</td>
<td>52.4</td>
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<tr>
<td>Live weight /bull</td>
<td>184</td>
<td>236.4</td>
<td>236.4</td>
<td>236.4</td>
<td>236.4</td>
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<tr>
<td>Consumption</td>
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<tr>
<td>Milk by family</td>
<td>28</td>
<td>38</td>
<td>38</td>
<td>38</td>
<td>38</td>
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<td>Milk by employees</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Made into butter</td>
<td>70</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Butter sold</td>
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Appendix G1. CDF of NPV for alternative irrigation technologies in Robit kebele

CDF of Net Present Value (NPV)
Appendix G2. StopLight chart for per family NPV in Robit kebele

Appendix G3. CDF of NCFI for base and alternative irrigation technologies in Robit kebele
Appendix H. Risk premiums ranking of alternative farming systems in Robit kebele

Appendix J. Nutrition simulation results

Calorie intake simulation results
Protein intake simulation results

CDF of protein intake per adult (grams)
Fat intake simulation results

CDF of fat intake per adult (grams)
Calcium intake simulation results
Iron intake simulation results

Probabilities of calcium intake Less Than 0.19 and Greater Than 0.35 grams

CDF of iron intake per adult (grams)
Vitamin A intake simulation results

CDF of Vit A intake per adult (grams)
### Summary results for nutritional and scenarios performance in Robit kebele

<table>
<thead>
<tr>
<th>Nutrition variables</th>
<th>Excess or deficit</th>
<th>Probability: nutrient cons &gt; min requirement</th>
<th>Improvement from baseline to alternative</th>
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<tbody>
<tr>
<td>Calories</td>
<td>Excess</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Proteins</td>
<td>Excess</td>
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</tr>
<tr>
<td>Fat</td>
<td>Deficit</td>
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<tr>
<td>Calcium</td>
<td>Deficit</td>
<td>0</td>
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</tr>
<tr>
<td>Iron</td>
<td>Excess</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>Excess</td>
<td>1</td>
<td>Yes</td>
</tr>
</tbody>
</table>