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Ex Ante Analysis of Small-Scale Irrigation Interventions in Dembiya

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1. Interpretive Summary

A collaboration between the USAID Feed the Future Innovation Laboratory for Small Scale Irrigation (ILSSI) and the project of the International Livestock Research Institute (ILRI) on Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES) was formally initiated through a memorandum of understanding in 2015. Both projects are involved in action research to assess irrigation technologies for smallholder farmers in Ethiopia and found mutual benefit in collaborating through data sharing and application of ILSSI's Integrated Decision Support System (IDSS). The collaboration is to provide results from the IDSS on production, environmental, and economic consequences of proposed interventions at selected LIVES sites, while providing ILSSI with additional sites in Ethiopia for evaluating small-scale irrigation (SSI) interventions.

This report summarizes ILSSI's analysis of proposed SSI interventions in Dembiya woreda, a LIVES site in the North Gondar zone of the Amhara region of Ethiopia. The majority of households in the area derive their livelihoods from crops and livestock production. The main staple food crops grown during the rainy season include teff, maize, millet, and sorghum, while irrigated crops such as tomatoes, pepper, potato, and onions are grown during the dry season. Chickpea is also a major staple food and can be grown in both the wet or dry seasons. Given Ethiopia's high groundwater potential, the cultivation of these crops could be expanded with the implementation of SSI in the dry season. However, decision makers have historically lacked means to assess the effects of increased SSI on crop production, farm-family economics, and environmental services.

In Dembiya, ILSSI proposed implementing SSI, using shallow groundwater and one of four alternative water-lifting technologies, to maximize production of high-value vegetable and fodder crops in the dry season. ILSSI evaluated the proposed SSI interventions by simulating and comparing two alternative farming systems:

i. continuous cropping of rainy-season crops (maize, teff, sorghum, and chickpeas), using current (minimal) irrigation and fertilizer rates; and
ii. multiple cropping of rainy-season crops (maize, teff, sorghum, and chickpeas) with irrigated, dry-season crops (tomato and fodder) on all irrigable cropland, using recommended fertilizer rates for the maize, teff, tomato and fodder crops.

Tomato and fodder were chosen as representative of irrigated dry-season crops to demonstrate not only the potential for increased farm family revenues and nutrition, but also for animal feed as it is relevant to the LIVES project. Napier grass was evaluated as a cash crop. The impacts on animal feed were not evaluated and therefore not discussed in this report. Additional vegetable and fodder crops will be modeled in future studies that reflect broader applications and implications on the livestock value chain.

Because comprehensive biophysical and watershed data was not available for Dembiya, this study used data and IDSS simulation results from a nearby ILSSI study site, Bahir Dar Zuria (BDZ) woreda, to analyze water availability, potential irrigable land, and crop yields in Dembiya. The two sites are located just 60 km apart and share similar rainfall patterns and soil properties. IDSS simulations of BDZ's Robit watershed indicated that there is large potential for additional SSI in the watershed, and that proposed SSI interventions could be sustained by the shallow groundwater recharge without affecting long-term groundwater storage or, in most respects, the environmental health of the watershed. Simulations of fodder, Napier grass, and alfalfa production, using current agricultural management practices (fertilizers, crop rotation, and irrigation), indicated that fodder yield is limited by nitrogen (with 22 nitrogen stress days per season) and temperature stress (with 3.8 temperature stress days per season). Napier grass yield is limited by temperature, water, and especially nitrogen stress (with 138 nitrogen stress days annually), and alfalfa yield is limited by water and temperature stress.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping system) on farm family economics in Abirjiha, a kebele in Dembiya. These simulations also compared the costs and benefits of four alternative water-lifting technologies: pulley-and-bucket irrigation, rope-and-washer pump, gasoline-motor pump, and solar-powered pump. In all, five scenarios (including the baseline, non-irrigated scenario) were simulated. Of the technologies examined, only the gasoline-motor pump met the irrigation water requirements for the proposed SSI interventions (i.e., for all 787 ha of irrigable land in the kebele). The gasoline-motor pump scenario generated the highest income and profits, despite high initial investment and capital costs (twice that of a rope-and-washer pump). The next-best performing scenarios used rope-and-washer or solar-pump irrigation. Individual farmers might benefit by spreading the costs of a gasoline-motor pump over more irrigated area (perhaps sharing a motor with other farmers) or by opting to use the less costly rope-and-washer pump.

In each of the alternative scenarios, the increase in farm revenue was due primarily to the sale of surplus irrigated tomatoes and fodder. Averaging results from the three best-performing alternative scenarios (gasoline-motor pump, rope-and-washer pump, and solar-powered pump), forecasted sales of tomatoes and fodder contributed 40% each of the total crops receipts and 41% and 39%, respectively, of the net cash (profit) for the five-year planning horizon.

Despite improvements in farm-family economics resulting from the proposed SSI interventions, nutritional deficiencies persisted (especially in Vitamin A) under the simulated, improved cropping systems. We would also, therefore, propose expanding the types of crops irrigated in the dry season to increase family nutrition and net cash income, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits.

Notably, IDSS simulations of the nearby BDZ woreda revealed very high soil erosion rates. The current and alternative cropping systems simulated for Dembiya, like those simulated for BDZ, could be unsustainable without substantial efforts to reduce soil erosion. Every effort should be made to identify and implement cropping systems that reduce rates of soil erosion. The evaluation of and comparison of alternative farming systems, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future study.

2. Introduction

The LIVES project aims to enhance income and gender-equitable wealth creation through the production and sale of high-value crops and livestock products, thereby supporting the government of Ethiopia in its efforts to transform the country's subsistence-based agriculture system to a more market-oriented system (Berhe 2013). Spanning four regions (Tigray, Amhara, Oromia, and SNNP), 31 districts, and 767 villages, the LIVES project was implemented by ILRI and the International Water Management Institute (IWMI), in partnership with the Ethiopian Institute of Agricultural Research, the Federal Ministry of Agriculture, the Regional Bureau of Agriculture/Livestock Development Agencies and the Regional Agricultural Research Institutes. The funding institution is the Canadian International Development Agency. Project operations started in April 2012 and are scheduled for completion in March 2018 (LIVES Project Brochure 2014).

ILSSI was formed to undertake research aimed at increasing food production, improving nutrition, accelerating economic development, and contributing to environmental protection in Ethiopia, Ghana and Tanzania. One of the major components of ILSSI includes the application of IDSS to quantitatively estimate the impact of SSI on production, environmental, and economic outcomes. The IDSS is comprised of a suite of spatially explicit agro-ecosystem models: the Soil and Water Assessment Tool (SWAT), the Agricultural Policy Environmental Extender (APEX), and the farm scale nutrition and economic simulation model (FARMSIM). The IDSS predicts short-term and long-term changes in crop and livestock production, farm economies, and environmental services produced by changing land uses, agricultural technologies and policies, climate, and water resources management, including SSI. The three models (and their sister and antecedent decision tools) have been used successfully for more than 25 years to address complex biophysical and economic issues in the United States and around the world. Designed to use readily available input data from global, national, and local sources, they can provide decision makers with reliable predictions of the production, environmental, and economic impacts of their actions.

The objective of this study was to use the IDSS to evaluate the economic and nutritional benefits of adopting different agricultural technologies, include irrigation and recommended fertilization, on farms in Dembiya woreda, a LIVES site in the in the Amhara region of the North Gondar zone of Ethiopia. Factors contributing to low crop production in the region include erratic weather conditions, low soil fertility, and ineffective management practices. Additionally, the dramatic shift in rainfall that occurs between the rainy season and the dry season restricts rain-fed cropping to the rainy season. For multiple cropping, irrigation is needed in the dry season.

Information about the area's natural resources, existing cropping systems, farm-family characteristics, and market conditions for agricultural products were obtained from a number of international, national, and local sources, including ILSSI simulations at the nearby BDZ study site. These data were then used as inputs to the IDSS modeling system.

The baseline farming-system scenario simulated was the typical farming system currently used by farmers in the region. It consisted of main crops (maize, teff, sorghum, and chickpeas) grown during the main rainy season, using current (minimal) irrigation. Proposed interventions included multiple cropping of rainy-season crops (maize, teff, sorghum, and chickpeas) with irrigated, dry-season crops (tomato and fodder) on irrigable cropland, and application of recommended fertilizer rates for the maize, teff, tomato and fodder crops. FARMSIM was used to simulate the effects of the proposed interventions on farm-scale economics in Abirjiha, a kebele in Dembiya, and to compare four alternative water-lifting technologies that could be used to implement SSI.

Parameterization, calibration, and execution of SWAT, APEX, and FARMSIM were closely coordinated, with input and output data exchanged in an integrated fashion to assure comparability of production, environmental, and economic results. This report describes the methodology, results, and implications of this study.

3. Materials and Methodology

3.1. Site description

The Dembiya study site is located in the North Gonder zone of the Amhara region of Ethiopia (fig. 1). The Dembiya watershed has an area of 5.22 ha and an average slope of 4.6%. Soil texture in the watershed is classified as clay.

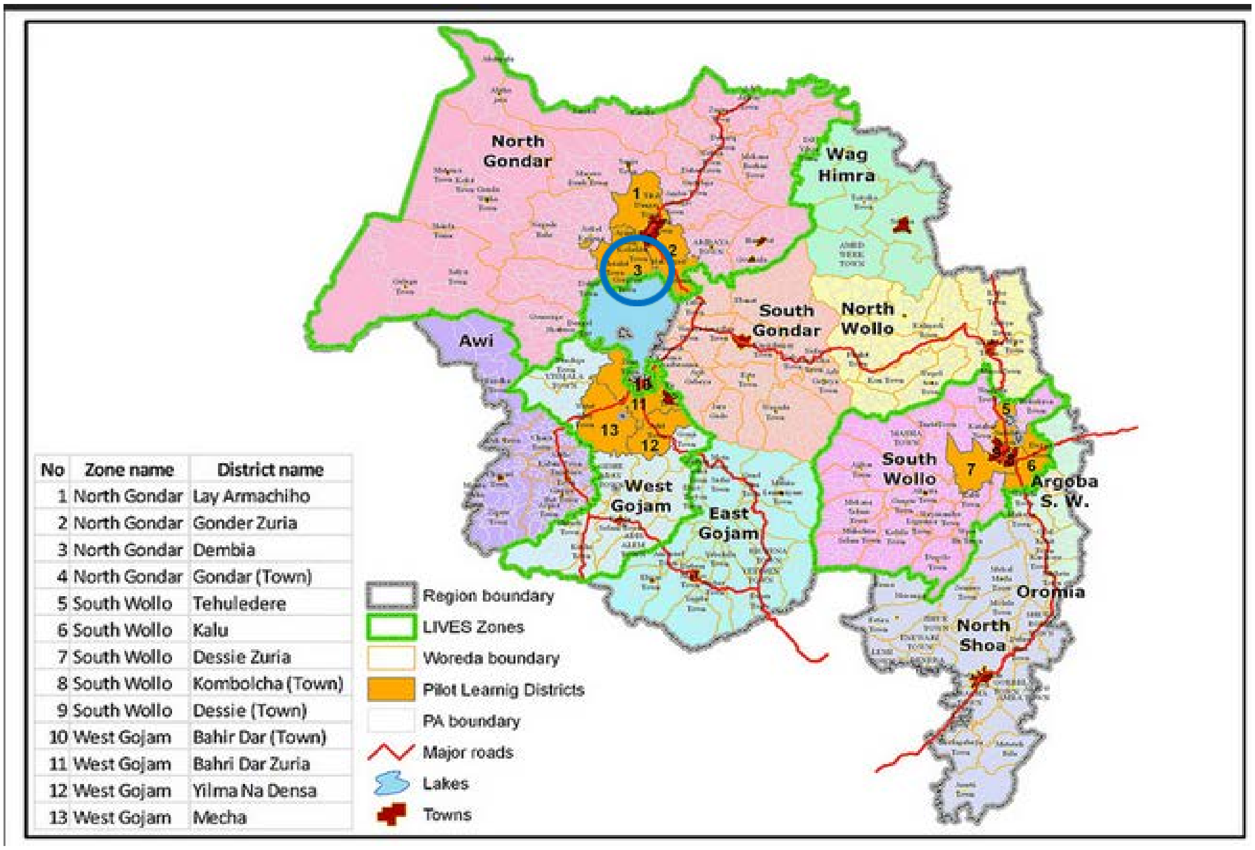


Figure 1. Location of the Dembiya woreda in North Gondar zone
Source: LIVES project website (https://lives-ethiopia.org/)

The Dembiya region has two distinct seasons: a prolonged dry spell from November to May, usually accompanied by severe water shortages; and a wet season from June to October (fig. 2). The annual average rainfall in Dembiya is approximately 1300 mm. The area encompassing Dembiya receives a monthly average solar radiation of 20MJ/m^2. These weather patterns restrict rain-fed cropping to a single cropping season; therefore, irrigation may improve crop and livestock production.

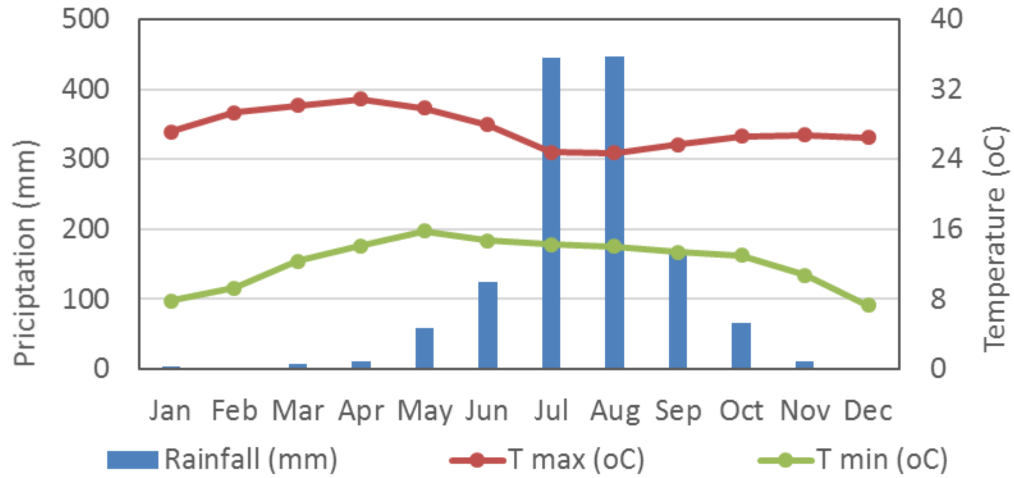


Figure 2. Monthly average rainfall and minimum and maximum temperatures (1980-2013) for Dembiya woreda

The predominant production system in the area is mixed crop and livestock production. Local households keep cattle, goats, sheep, and chickens. Farmers raise cattle to meet draught power requirements and to produce milk, meat and butter and breeding stock for sale and family consumption. The main staple food crops include teff, maize, millet, sorghum and chickpeas (Teshome 2016). Crops are grown using both rain and irrigation water. Major field crops are grown and harvested during the rainy season from March to September. Irrigated crops such as tomatoes, chickpeas, pepper, potato and onions are grown during the dry season from October to January, with shallow wells serving as the main source of irrigation water.

Research studies show that agricultural inputs (e.g., fertilizers, irrigation and improved seeds) are below government-recommended rates (Teshome et al. 2009; Endale, 2011; Rashid et al., 2013). A 2014 LIVES survey also indicated that levels of agricultural and livestock inputs (e.g., animal breed improvements) in Dembiya woreda are low, and that only 7% of households in Abirjiha kebele irrigate fruits and vegetables. Only one out of 48 households surveyed reported owning a motor pump. The level of farm labor hired for agricultural production is also low, since family members are expected to perform most of the agricultural tasks required for farming. It is also worth noting that the use of actual crops to feed animals is not common; most animal feed comes from crop residues.

3.2 Model input data

Input data used in this study included:

3.2.1. Hydro-meteorological data. Hydro-meteorological data for Dembiya was not available; however, this data was available for BDZ, an ILSSI study site located less than 60 km from Dembiya. Accordingly, hydro-meteorological data from the BDZ study site (and the underlying Robit watershed) was used as input data for Dembiya simulations. Hydro-meteorological data for the ILSSI site was collected from a nearby station owned by the Ethiopian Meteorological Agency, and missing meteorological data was filled in with Climate Forecast System Reanalysis (CFSR) data collected from the Texas A&M University Spatial Sciences website (globalweather.tamu.edu). Additional details regarding the data and simulations at the ILSSI study site are compiled in the *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Robit, attached to this report as Appendix A.

3.2.2 Spatial data.

a) A global land use map from Land Use Systems (LUS) Version 1.1, collected from the FAO GeoNetwork, was used to characterize the watershed. The land use map was developed by combining more than 10 global datasets, and has a spatial resolution of approximately 10 km.

b) A 30-m resolution Digital Elevation Model (DEM) from SRTM Enhanced Shuttle Land Elevation Data (USGS EarthExplorer) was used to characterize the watershed. The DEM voids were filled with the predecessor, 90-m resolution SRTM DEM after resampling the grid to 30-m resolution.

c) A digital global soil map from the FAO-UNESCO Soil Map of the World (FAO and ISRIC 2013) was used to extract soil properties. The soil map includes percent soil texture, organic carbon content and other relevant information at depths of 0-100 cm and 100-200 cm.

3.2.3 Crop management data. Crop management data were obtained from regional agricultural specialists from ILRI in Addis Ababa. Appendix B1 sets forth detailed crop management and fertilization schedules for crops, as simulated with APEX.

3.2.4 Crop yield data. Crop yield data for APEX calibration and validation were obtained from:

a) a 2013 survey by the International Food Policy Research Institute (IFPRI) of household crop management practices (including fertilizer type and application rates and dates), which indicated that fodder yield in the area ranges from 2.18 to 3.59 t/ha.

b) USAID estimates of approximate alfalfa and Napier grass yields.

This study was limited by a lack of yield data to calibrate the APEX model parameters to see the effects of management practices on the environment and crop yields. Results can be improved with observed forage yields in those areas.

3.3 Methods

3.3.1 SWAT and APEX model setup and calibration. SWAT and APEX were used to assess soil, water and crop growth characteristics at the watershed and field scale, respectively. Due to a lack of biophysical and watershed information for Dembiya, as noted in Section 3.2.1, this study used data and simulation results from BDZ woreda to analyze water availability and potential irrigable land in Abirjiha kebele in Dembiya. The two sites are located just 60 km apart and share similar rainfall patterns and soil properties.

The SWAT model for the Robit watershed in BDZ was first set up for the entirety of the watershed, and then subdivided into subbasins. Using SWAT, flow and sediment were simulated by transferring the calibrated and validated model parameter sets from the nearby Gumera gauging station (MoWE 2012). This process is detailed further in the *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Robit, attached to this report as Appendix A.

APEX was set up for identical subareas (of the same shape and size as SWAT's subbasins) to guarantee that streamflow volume and sediment yield were comparable between SWAT and APEX. For APEX, a sub-watershed corresponding to an identical subarea from SWAT was selected. The flow and sediment yield of the selected subarea as estimated by SWAT was used to calibrate APEX flow and sediment parameters. APEX calibration was achieved by using the automatic calibration tool APEX-CUTE (auto-Calibration and UncerTainty Estimator (Wang et al. 2014). After calibration to replicate flow and sediment yield outputs of SWAT, APEX crop parameters were calibrated to match with the average ILRI yield survey for fodder. Napier and alfalfa simulations were calibrated to match with the USAID approximate crop yield ranges.

APEX-simulated flow and sediment were calibrated for the period from 1983 to 2013. We applied the Penman-Monteith method to estimate potential evapotranspiration, SCS Curve number for estimating runoff and the Modified Universal Soil Loss Equation (MUSLE) to estimate soil erosion. For the baseline simulation, after assigning the current management schedules (fertilization type, rates, and application dates), crops are grown year after year on the same land.

3.3.2 Alternative scenarios simulated with APEX. ILSSI used the APEX model to simulate production of Napier grass, alfalfa, and fodder (vetch + oats) and to observe simulated crop yields. Scenarios simulated with APEX included:

a) Fodder simulation: Oats and vetch were planted as mixed crops in a ratio of 4 to 1 and grown continuously in the dry season; irrigation was applied automatically to fill the root zone soil moisture to field capacity. Detailed descriptions of the crop management practices for fodder, as simulated by APEX, are set forth in Appendix B1.

b) Napier grass and alfalfa simulation: Alfalfa and Napier grass were planted as perennial crops. In the dry season, supplemental irrigation was applied to fill the root zone soil moisture to field capacity; a maximum annual irrigation volume of 800 mm of water was budgeted. The first alfalfa harvest was scheduled 6 months after planting, with a subsequent cutting every 60 days for 5 years before replanting. The first Napier grass harvest was scheduled 3 months after planting, followed by a cutting every 60 days for 3 years before replanting. Detailed descriptions of the crop management practices for alfalfa and Napier grass, as simulated by APEX, are set forth in Appendix B1.

Note that the APEX model was also used to simulate 32 years of historical yields for grain crops (teff, maize, and sorghum), chickpeas and vegetables (onion, tomato and potato), alongside fodder. These yields were used as input in FARMSIM to evaluate the total economic and nutrition impacts at the household level.

3.3.3 Economic Analyses. FARMSIM simulated a representative farm in the Abirjiha kebele in Dembiya for five years to provide an economic perspective on promising SSI interventions. In the baseline scenario, maize, teff, sorghum, and chickpeas were grown as monocrops during the main rainy season, using shallow tillage with animal traction, and current fertilizer application rates. Water stress was not a constraint for the grain crops and chickpeas, since they were grown during the main rainy season. However, the few plots in Abirjiha kebele that were allocated to dry-season tomato had very limited or no irrigation. Current applied fertilizer rates were minimal as well. The use or lack of improved seeds was not discussed in this study.

In addition to the baseline scenario described above, FARMSIM simulated four different alternative scenarios. All of the four alternative scenarios incorporated: (1) cultivation of rainy-season maize, teff, sorghum, and chickpeas, as in the baseline scenario; (2) the addition of irrigated, dry-season tomatoes and fodder on irrigable cropland within the kebele (i.e., those areas with irrigation-appropriate soils and slopes less than 8% - a total of 787 ha), using one of four alternative water-lifting technologies; and (3) application of recommended rates of fertilizers for maize, teff, tomato and fodder. Napier grass was considered for both the baseline and alternative scenarios but with no technology. Each of the four alternative scenarios employed one of four water-lifting technologies for irrigation: pulley-and-bucket; rope-and-washer pump; gasoline-motor pump; and solar-powered pump. Photos of these systems are attached as Appendix C to this report. These technologies were evaluated as to their capacity to provide necessary irrigation water to a maximum irrigable cropland of 787 ha, taking into account their varying costs and pumping rates.

In each of the four alternative scenarios, the area allocated to tomato and fodder production was limited by the pumping capacity of the water-lifting technology employed in that scenario assuming equal number of irrigation hours per season. The area allocated to each dry season crop increased (by equal amounts for each crop) as pumping rates (and accordingly, total irrigated acreage) increased. In each of the alternative scenarios, the dry-season tomato and fodder were irrigated as required to prevent water stress, and maize, teff, and tomato were fertilized at recommended rates as set forth in Appendix B2.

The FARMSIM model was run 500 times for each of the five scenarios—the baseline scenario and four alternate scenarios—to sample variation in crop yields due to weather and other stochastic variables. In the model, crop production is used to meet family, seed, and livestock needs first, and any surplus is assumed to be sold. Receipts are simulated as the product of stochastic prices and residual crop and livestock production. Expenses are calculated by summing the product of hectares planted and initial costs of production from the survey. Cash expenses for the family are provided in the survey information.

To determine which of the five scenarios would be most beneficial to farm families, three types of economic indicators were calculated: net present value, net cash farm income, and ending cash reserves. Net present value is the present value of family withdrawals and the change in real net worth over a five-year planning horizon; net cash farm income equals receipts minus cash expenses; and ending cash reserves equal total cash inflow minus total cash outflow on December 31 of the last year of the planning period. The performance of the five scenarios as estimated by each of the three indicators was displayed graphically as a cumulative distribution function and as a "stoplight graph."

4. Results and Discussion.

4.1 Stream Flow and Crop Yield Calibration.

4.1.1 SWAT calibration. SWAT model calibration was performed from 1993 to 2000 and provided a Nash-Sutcliff efficiency (NSE) value of 0.83, and a Percent Bias (PBIAS) value of 5.4%. According to Moriasi et al. (2007), SWAT performance in simulating Gumera river basin was very good, based on NSE and PBIAS values. The model was validated from 2001 to 2007 and provided an NSE value of 0.84 and PBIAS of 15.3%. The stream flow plot between observed and simulated values showed a general agreement, except that a few peaks were not captured by the model (fig. 3). Calibrated SWAT hydrological parameters (table 1) were provided to the APEX model. Likewise, calibrated crop-related parameters were obtained from APEX simulations.

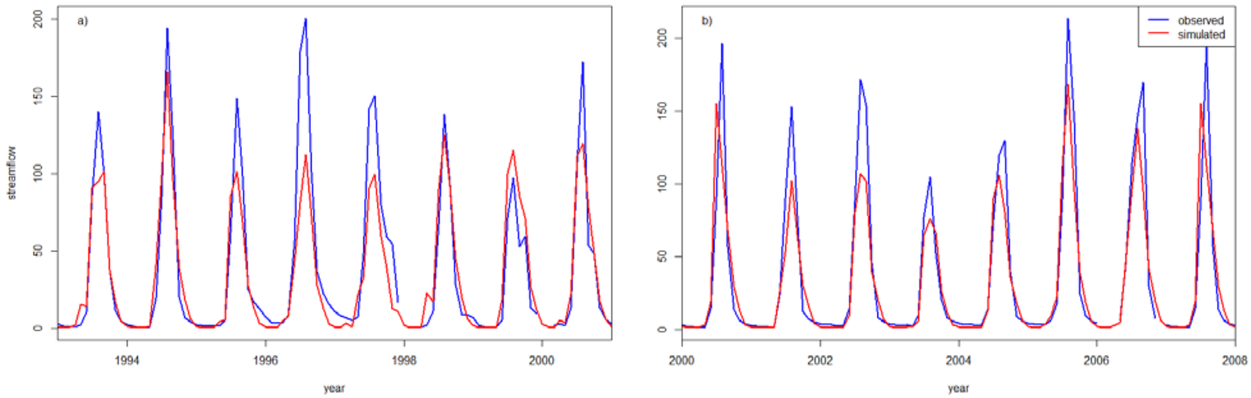


Figure 3. Observed vs simulated stream flow plot for Gumera river basin: a) calibration, and b) validation.

Table 1. Calibrated SWAT parameters for the Robit watershed

No	Parameter	Value
1	*r__CN2.mgt	-0.045
2	v__ALPHA_BF.gw	0.273
3	a__GW_DELAY.gw	-12.95
4	a__GWQMN.gw	63
5	a__GW_REVAP.gw	0.07306
6	v__ESCO.hru	0.794
7	v__CH_K2.rte	12.42
8	r__SOL_AWC().sol	0.0278
9	a__REVAPMN.gw	172.5

**r_ means the existing parameter value is multiplied by (1+ a given value), v_ means the existing parameter value is to be replaced by the given value, and a_ means the given value is added to the existing parameter value.*

4.1.2 APEX streamflow and sediment yield calibration. APEX simulated streamflow and sediment yield were calibrated from the period 1983 to 2013. The performance of the model for the streamflow and sediment yield for the calibration period was reasonably good, with a Nash-Sutcliff Efficiency (NSE) value of 0.86 and an R-square value of 0.99. Figure 4 shows the comparison of monthly APEX and SWAT flow simulations. Both SWAT and APEX share input datasets for land use, soil, elevation, weather, and crop management, and use the same methods for estimating potential evapotranspiration (Penman-Monteith), runoff (SCS Curve number method), and soil erosion (Modified Universal Soil Loss Equation, or MUSLE); however, differences in the SWAT and APEX valuations result because SWAT calculates flow at the HRU level, whereas APEX calculations are field-based, and consider the dominant land use, soil and slope of a selected subarea rather than the unique features of each of the HRUs within a subarea.

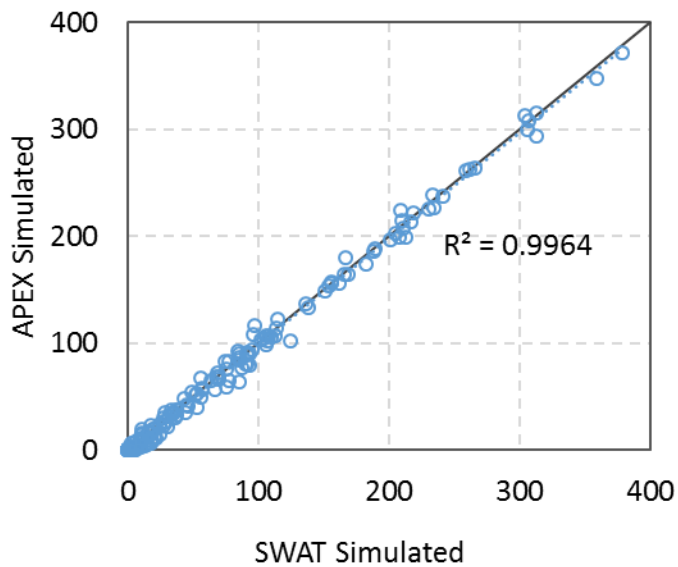


Figure 4. Scatter plot of monthly SWAT and APEX simulated flow for Robit watershed (1983-2013)

The calibrated APEX model simulates the general hydrologic processes of runoff, baseflow, infiltration, percolation, and evapotranspiration components at the watershed level. The general water balance components of the watershed show that evaporation and surface runoff are the dominant contributing processes.

4.2 Hydrology. As noted in Sections 3.2.1 and 3.3.1, this study used data and simulation results from BDZ woreda to analyze water availability and potential irrigable land in Abirjiha kebele. Adequate biophysical and watershed data was not available for Dembiya, and the two sites are located just 60 km apart and share similar rainfall patterns and soil properties. IDSS simulations of BDZ's Robit watershed indicated that there is large potential for additional SSI in the watershed, and that proposed SSI interventions could be sustained by the shallow groundwater recharge without affecting long-term groundwater storage or, in most respects, the environmental health of the watershed. Notably, simulated soil erosion rates were very high in Robit, suggesting that the current and alternative cropping systems simulated in the Robit study could not be sustained without substantial efforts to reduce soil erosion. The Robit study is described in the *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Robit, attached to this report as Appendix A.

4.3 APEX forage yield assessment.

4.3.1 Fodder simulation. The simulations indicated that nitrogen and temperature stress are the major limiting factors for each of the three sites. The Dembiya site has 22 nitrogen stress days a season, and 3.8 temperature stress days a season (fig. 5).

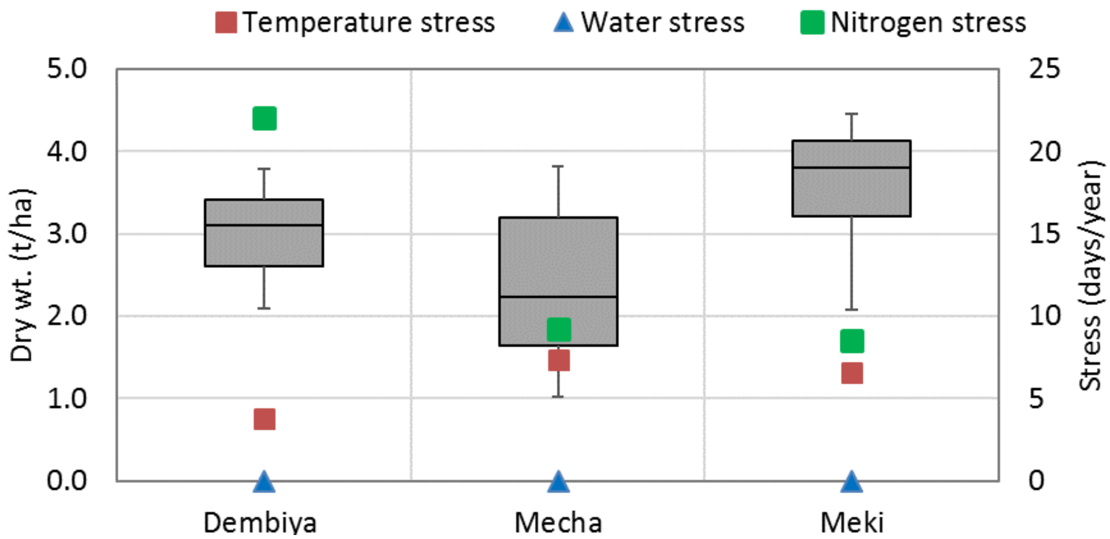


Figure 3. Comparison of fodder yield in Dembiya, Mecha, and Meki (1983 to 2013).

4.3.2 Napier grass and alfalfa simulation. Figure 6 shows simulated alfalfa and Napier grass yields (t/ha) for the Dembiya site, with nitrogen, temperature and water stress days plotted in the secondary y-axis. Napier yield was limited by nitrogen temperature, and water stress. On average, annually, Napier grass was subject to nitrogen stress for 138 days. Alfalfa yields were limited by water and temperature stress.

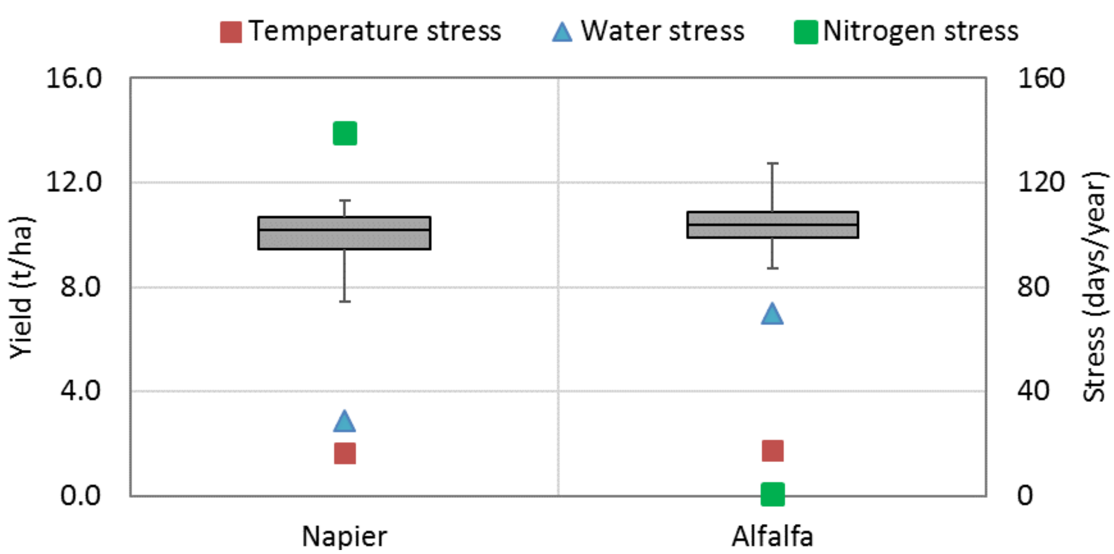


Figure 4. Yields of continuously-planted alfalfa and Napier grass, grown with supplemental irrigation at the Dembiya site (1983 to 2013).

This study was limited by a lack of yield data to calibrate the APEX model parameters to see the effects of management practices on the environment and crop yields. Results can be improved with observed forage yields in those areas.

4.4 FARMSIM economic analyses. The analyses that follow reference the baseline scenario and FARMSIM alternative scenarios 1-4, discussed in detail above. In the baseline scenario, maize, teff, sorghum, and chickpeas are grown as monocrops during the main rainy season, using shallow tillage with animal traction, and current fertilizer application rates. In each of the alternative scenarios (alts. 1-4), maize, teff, sorghum, and chickpeas are grown in the wet season, with maize and teff fertilized at improved rates. In addition, irrigation with one of four different water-lifting technologies (as specified below) enables cultivation of dry-season tomato and fodder, with tomato fertilized at improved rates. The baseline scenario and four alternative scenarios are specifically defined as follows:

Baseline: no irrigation + current fertilizers

Alt.1: irrigation of tomato/fodder with pulley and bucket + recommended fertilizers

Alt.2: irrigation of tomato/fodder with rope-and-washer pump + recommended fertilizers

Alt.3: irrigation of tomato/fodder with motor pump + recommended fertilizers

Alt.4: irrigation of tomato/fodder with solar pump + recommended fertilizers

Note that the evaluation did not include the capital costs of drilling wells, as these costs can vary greatly from household to household, depending on the type of well (Namara et al. 2011). Only the capital costs related to the water-lifting technology and its operating costs were included in the model.

Other simulation assumptions: First, to show the full potential of adopting new technologies, we assumed that the alternative farming technologies (alternative scenarios) simulated in this study were adopted at 100% by farmers. Second, the markets were assumed to be accessible and function at a competitive level with no distortion where the supply and demand determine the market prices. However, in the 5-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.

The farm-level simulation results for the five scenarios showed differences not only between the baseline and the alternative scenarios but also among the alternative scenarios in terms of net present value (NPV), net cash farm income (NCFI), and ending cash reserves (EC).

4.4.1 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 results, as illustrated by the CDF graph in figure 7a, indicate clearly that it is worth investing in irrigation and fertilizer application. The application of recommended fertilizers on grain and vegetable crops, together with the irrigation of tomato and fodder crops using rope-and-washer, motor, or solar pumps (Alts. 2, 3, and 4, respectively) showed outstanding performance, in that their CDF values lie to the right of the other scenarios for all 500 draws of the simulation model. Notice that the motor pump scenario (Alt. 3) has the highest NPV value compared to the rope-and-washer and solar pump scenarios (Alts. 2 and 4, respectively). The fourth best scenario involves the use of a pulley/bucket irrigation system (Alt. 1). All of the alternative scenarios show higher NPV values than the baseline scenario.

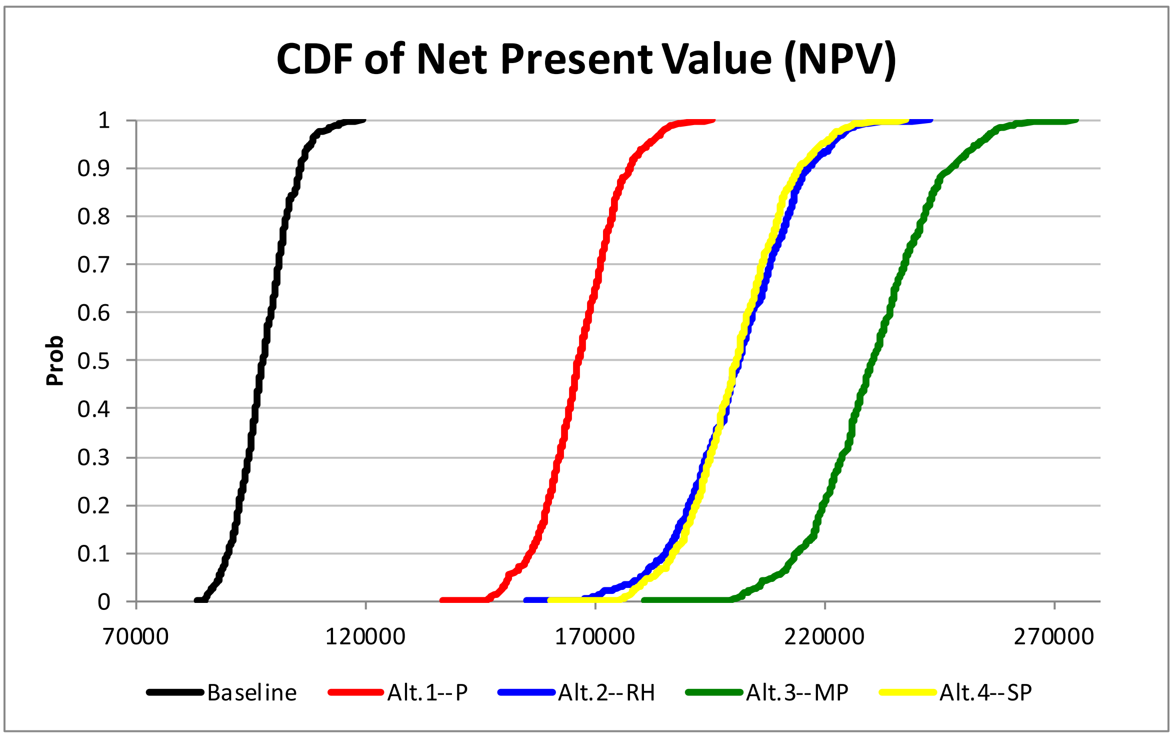


Figure 7a. CDF of NPV for alternative irrigation technologies in Abirjiha kebele, Dembiya

Legend					
Baseline :	**No irrigation**	Alt.2--RH :	**Rope & Washer pump**	Alt.4--SP :	**Solar pump**
Alt.1--P :	**Pulley and Bucket**	Alt.3--MP :	**Motor pump**		

The stoplight chart below (fig. 7b) presents the probabilities of NPV being less than 100,000 ETB (Ethiopian Birr) (red), greater than 214,000 ETB (green), and between the two target values (yellow) for the five-year planning horizon. The target values are: NPV for the lowest-performing scenario (baseline scenario) for the lower bound; and the average of NPV for the two best-performing alternative scenarios (Alts. 2 and 3) for the upper bound. In the baseline scenario, there is a 63% chance that NPV will be less than 100,000 ETB and a 0% chance that NPV will exceed 214,000 ETB. In the rope-and-washer and solar pump scenarios (Alts. 2 and 4, respectively) there is a 14% and 11% probability, respectively, of generating NPV greater than 214,000 ETB. In contrast, in the motor pump scenario (Alt. 3), there is a 90% probability that NPV will exceed the upper target of 214,000 ETB. These results suggest that investment in motor-pump-based irrigation will increase the irrigated area, offset the costs, and pay large dividends by increasing income and wealth.

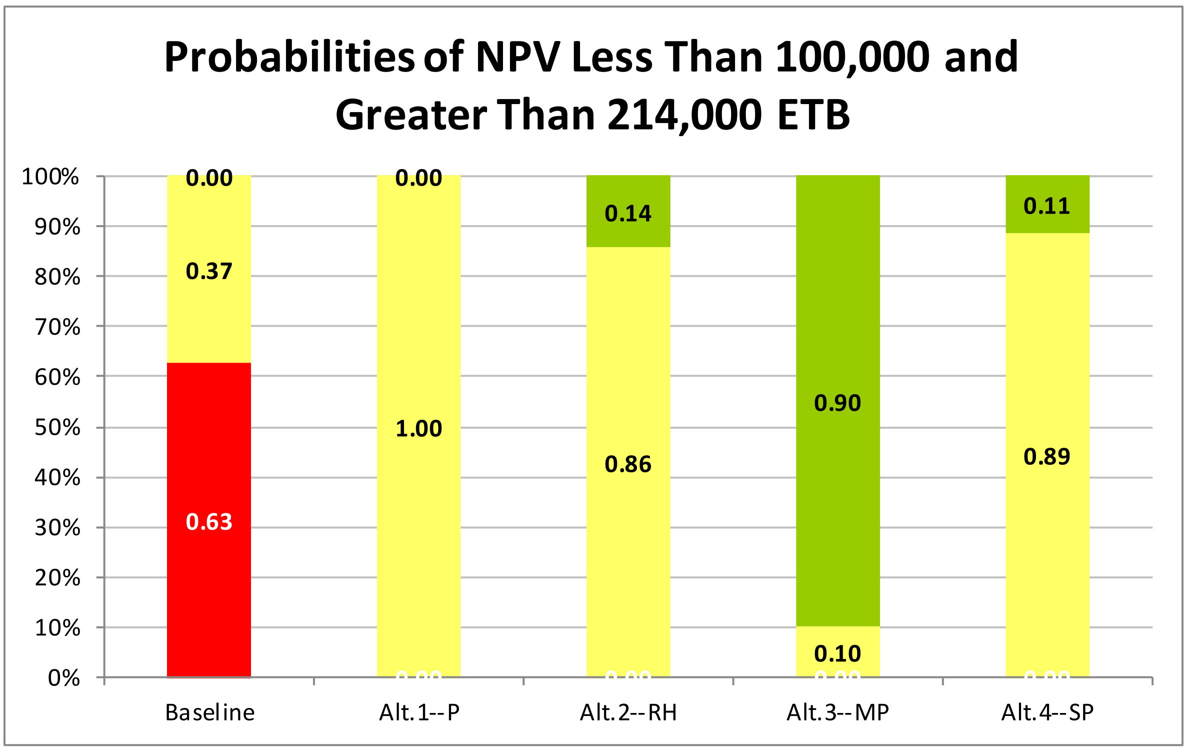


Figure 7b. StopLight chart for per-family NPV in Abirjiha kebele, Dembiya

4.4.2 NCFI

Annual NFCI measures the amount of profit generated by the farm for the baseline and alternative scenarios. The simulation results (fig. 8a) show that the motor pump scenario (Alt. 3) generated higher NCFI than the baseline and other alternative scenarios at all probability levels, in that its CDF values lie completely to the right of the other scenarios. The rope-and-washer and solar pump scenarios (Alts. 2 and 4, respectively) generated the next highest levels of NCFI.

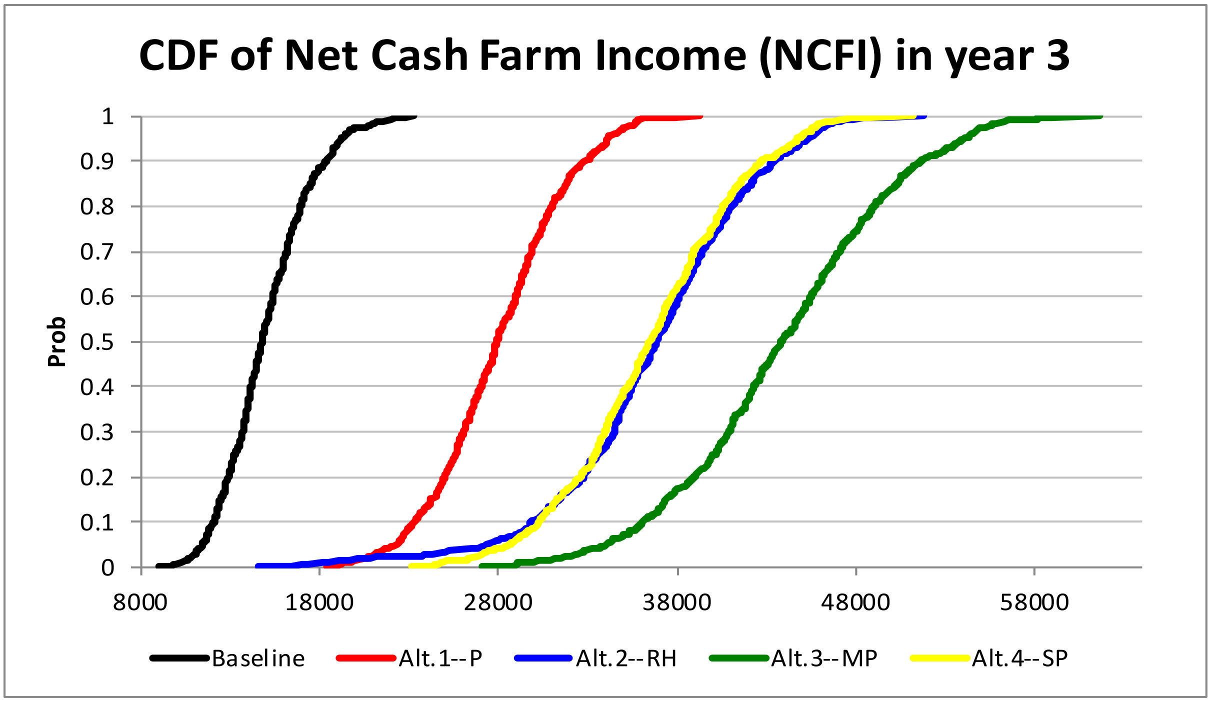


Figure 8a. CDF of NCFI for Abirjiha kebele, Dembiya

The stoplight chart for NCFI in year 3 of the 5-year planning horizon (fig. 8b) shows that, for a representative farm in the baseline scenario, there is a 68% probability that NCFI will be less than 16,000 ETB and a 0% probability that NCFI will exceed 40,000 ETB. In contrast, in the motor pump scenario (Alt. 3), there is a 75% chance that annual NCFI will exceed 40,000 ETB and just a 25% probability that NCFI will fall between 16,000 and 40,000 ETB. In the rope-and-washer and solar pump scenarios (Alts. 2 and 4, respectively), there is on average a 26% probability that NCFI will exceed 40,000 ETB, and a 74% probability that annual NCFI will fall between 16,000 and 40,000 ETB. The pulley/bucket scenario (Alt. 1), though inferior to the other alternative scenarios, performed better and generated higher profits than the baseline scenario.

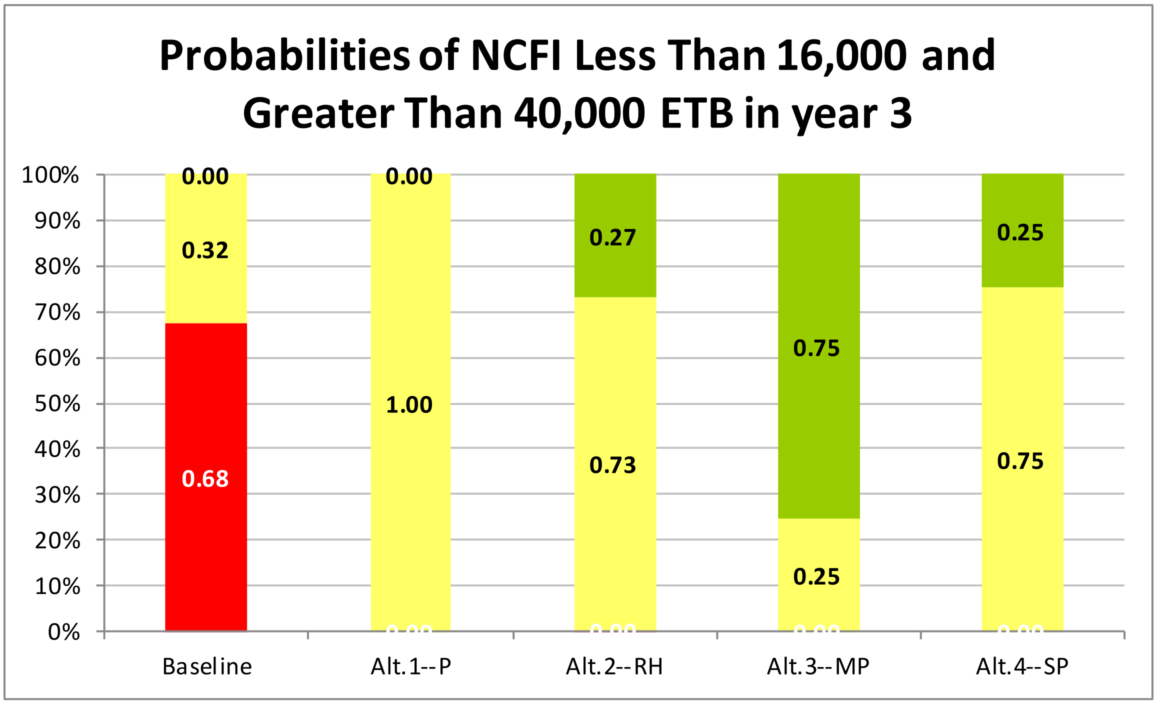


Figure 8b. StopLight chart for per-family NCFI in Abirjiha kebele, Dembiya

4.4.3 EC

The EC simulation results (figs. 9a and 9b) highlight once again the superior performance of the motor, solar and rope-and-washer pump scenarios (Alts. 3, 4 and 2). The pulley/bucket scenario (Alt. 1) performed better than the baseline scenario but generated lower EC compared to alternative scenarios 2, 4 and 3.

The stoplight chart for EC (fig. 9b) shows that, in the baseline scenario, there is a 52% probability that EC in year 5 will be less than 75,000 ETB and a 0% probability that EC will exceed 200,000 ETB. Alternatively, in the motor pump scenario, there is a 0% probability that EC will be less than 75,000 ETB, and a 92% probability that EC will exceed 200,000 ETB. The second best choices are the rope-and-washer and solar pump scenarios (Alts. 2 and 4, respectively), which have a 10% and 9% chance, respectively, of generating EC greater than 200,000 ETB. The pulley/bucket scenario (Alt.1) generates higher EC than the baseline scenario.

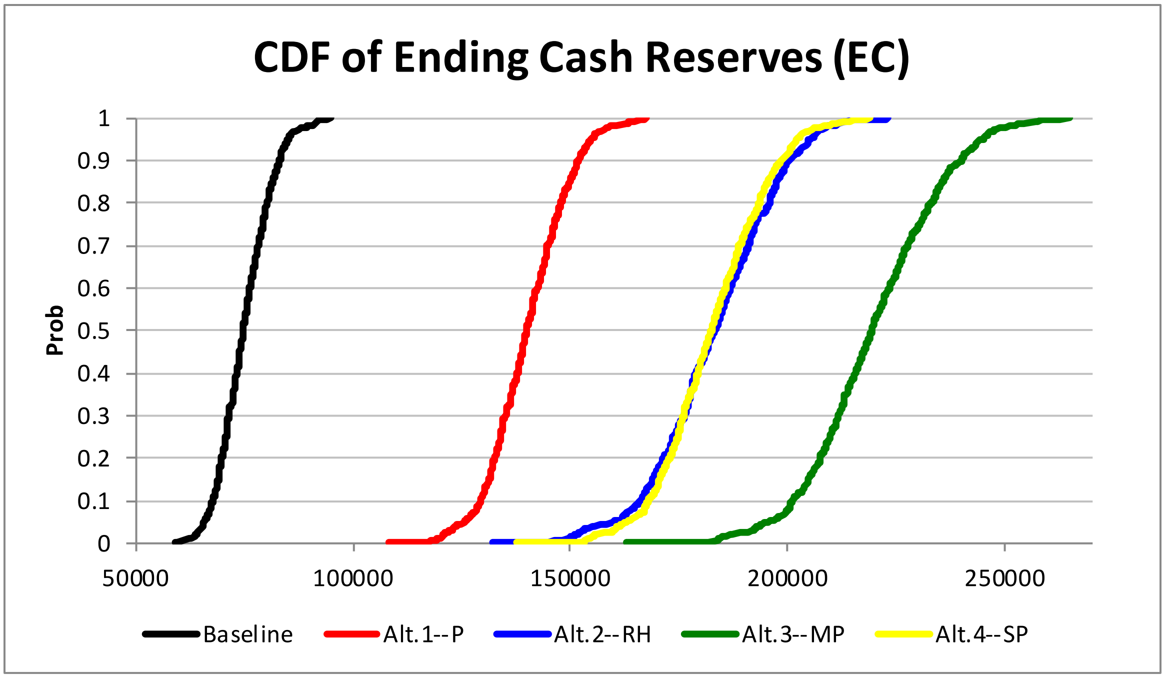


Figure 9a. CDF of EC in Abirjiha kebele, Dembiya

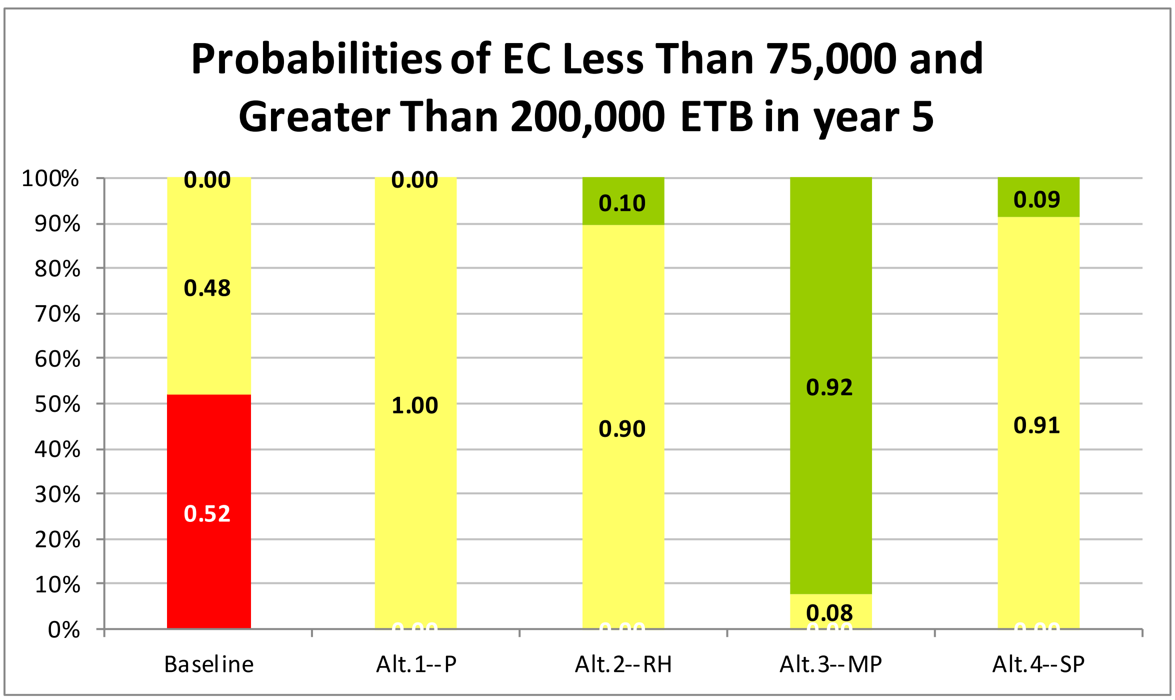


Figure 9b. StopLight chart for per-family EC in Abirjiha kebele, Dembiya

Since grain crops in Dembia are mainly used for family consumption, the increases in farm revenue in each of the alternative scenarios were due in majority to the sale of surplus tomato and fodder. Averaging results from the three best-performing alternative scenarios (Alts. 3, 2 and 4), forecasted sales of tomatoes and fodder contributed 40% each to the total crops receipts and 41% and 39%, respectively, of the net cash (profit) for the five-year planning horizon. Teff surprisingly contributed 14% of the total revenue, as its consumption at the household level stood at 55%, a lower percentage than normal.

4.4.4 Nutrition results

In general, 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; however, surplus crops can be sold at market, and resulting revenues can be used to buy food items needed to complement nutrition requirements.

In Abirjiha kebele, the quantities of crops and livestock products consumed by families in the baseline scenario meet minimum daily requirements for iron, but are insufficient to meet minimum daily requirements for calories, fat, calcium, vitamin A, and protein; moreover, the LIVES survey shows that individual households do not currently purchase additional quantities of food or receive any food aid to supplement the food that they produced.

Table 2 summarizes simulation results based on the fifth year forecast from the 5-year planning horizon. Specifically, table 2 lists the nutritional variables measured, the quantity of each nutrient consumed as compared to the minimum daily requirement for each nutrient, and whether the amounts consumed in the alternative scenarios were an improvement as compared to the baseline scenario.

Simulated levels of nutrition variables (calories, proteins, fat, calcium, iron and vitamin A) available to farm families did not increase in the alternative scenarios (table 2), probably because yields of all crops except tomatoes did not increase substantially in the alternative scenarios. Clearly food supplements (either through purchase or farming) to increase the intake for calories, fat, calcium and vitamin A will be needed to meet the nutritional requirements and the well-being of the families in Abirjiha kebele.

Table 2. Summary results for nutrition and scenario performance

Nutrition variables	**Performance**		
	Excess or deficit	Probability: nutrient cons > min required	Improvement from base to alternative
Calories	Deficit	0.76	Yes
Proteins	Excess	1	Yes
Fat	Deficit	0	Yes
Calcium	Deficit	0	Yes
Iron	Excess	1	Yes
Vitamin A	Deficit	0	Yes

Simulation results for each of the nutrition variables analyzed in this study are discussed in greater detail below.

a. Calorie intake simulation results

Grain or cereal crops represent the basic staple food and a source of calories (or energy) in many developing countries with agriculture-based economies, including Ethiopia (Gierend et al. 2014). In this study, the grain crops analyzed are teff, maize, and sorghum. Survey information shows that, on average, 66% of all grains produced by households in Abirjiha kebele are consumed at home. Despite allocating large land areas to the grain crops, simulation results (fig. 10a) show a deficit in calorie intake in baseline scenario for a typical household in Abirjiha kebele. In fact, the average daily calorie intake of 1460 calories, in baseline scenario, falls short of the daily minimum requirement of 1750 calories while the alternative scenario average of 1860 calories is above the minimum requirement. Other simulation scenarios show that an increase in purchase of 1 to 2 Kgs of maize per week or an increase from 55% to 75% fraction consumed of teff at the household level would remove the deficit in calorie intake.

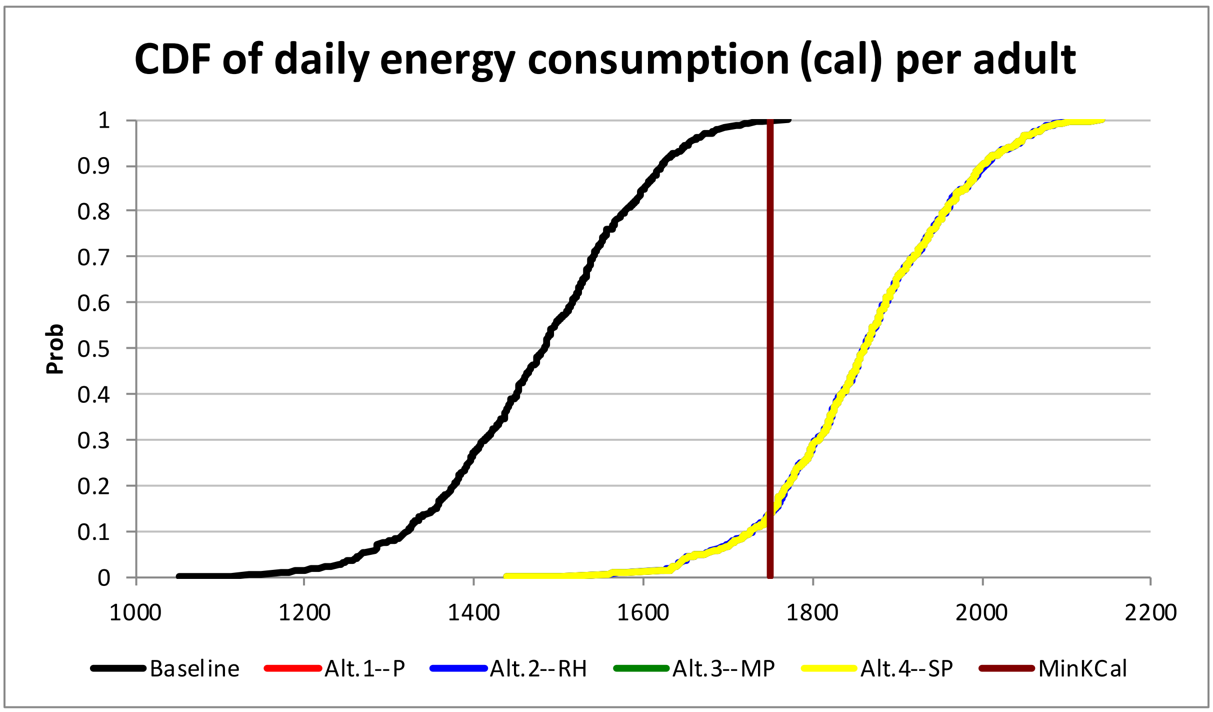


Figure 10a. CDF of daily energy consumption per AE on a farm in Abirjiha kebele

The StopLight chart for daily energy consumption per AE is presented in figure 10b. In the baseline scenario, there is a 49% chance that daily energy consumption per AE will be less than 1480 calories (average for the baseline scenario), and a 51% chance that it will be between 1480 and 1750 calories. Note that the high target value of 1750 calories is the actual daily minimum requirement for an AE. There is however an 86% probability of exceeding this requirement for the four alternative scenarios. The introduction of improved production practices (fertilizer and irrigation) in the alternative scenarios increased significantly the probability of meeting the daily energy requirement in the diet.

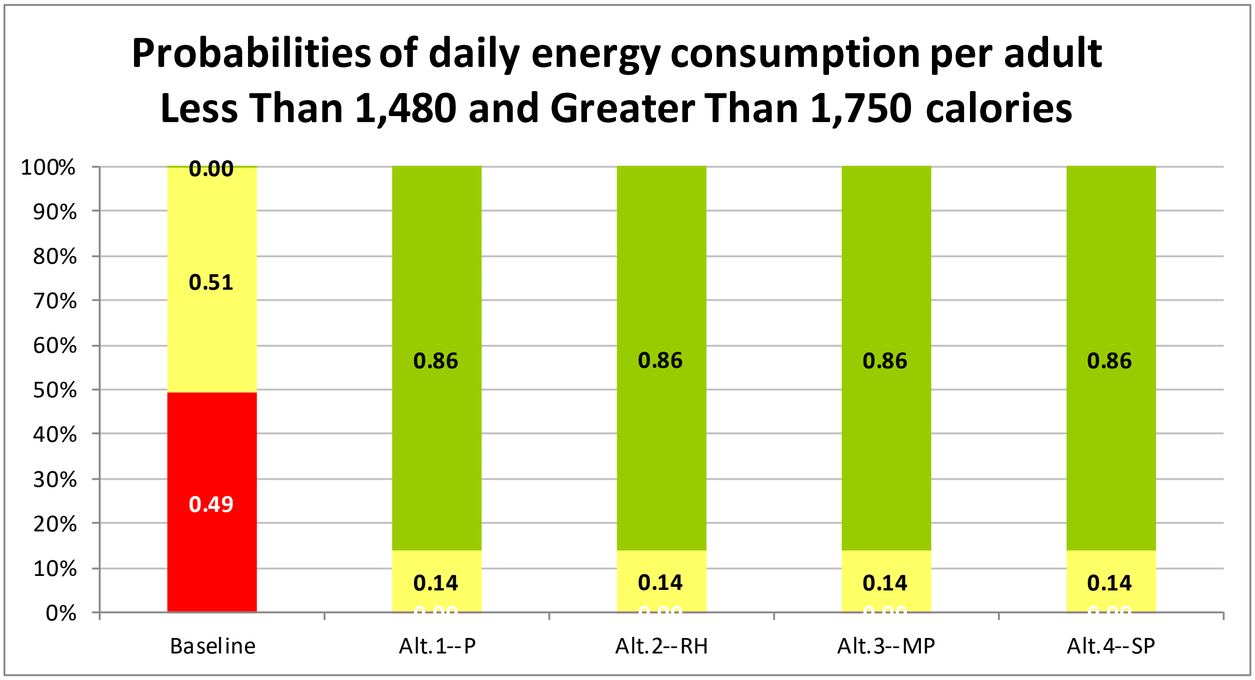


Figure 10b. StopLight Chart for daily energy consumption per AE on a farm in Abirjiha kebele

b. Protein intake simulation results

Animal products are often the main source of proteins at the household level. However, surveys showed that the majority of the proteins consumed in Abirjiha kebele were obtained from crops rather than animal products. This is a general pattern in many developing countries, and particularly in Ethiopia where the per capita consumption of livestock products, especially meat, is extremely low (Tafere and Worku 2012). The simulation results set forth in figure 11a, below, show that households in both the baseline and alternative scenarios meet the minimum daily requirement for proteins intake (41 gr/AE), except for a small fraction (10%) in the baseline scenario. There was very a clear improvement in the alternative scenarios as compared to the baseline scenario.

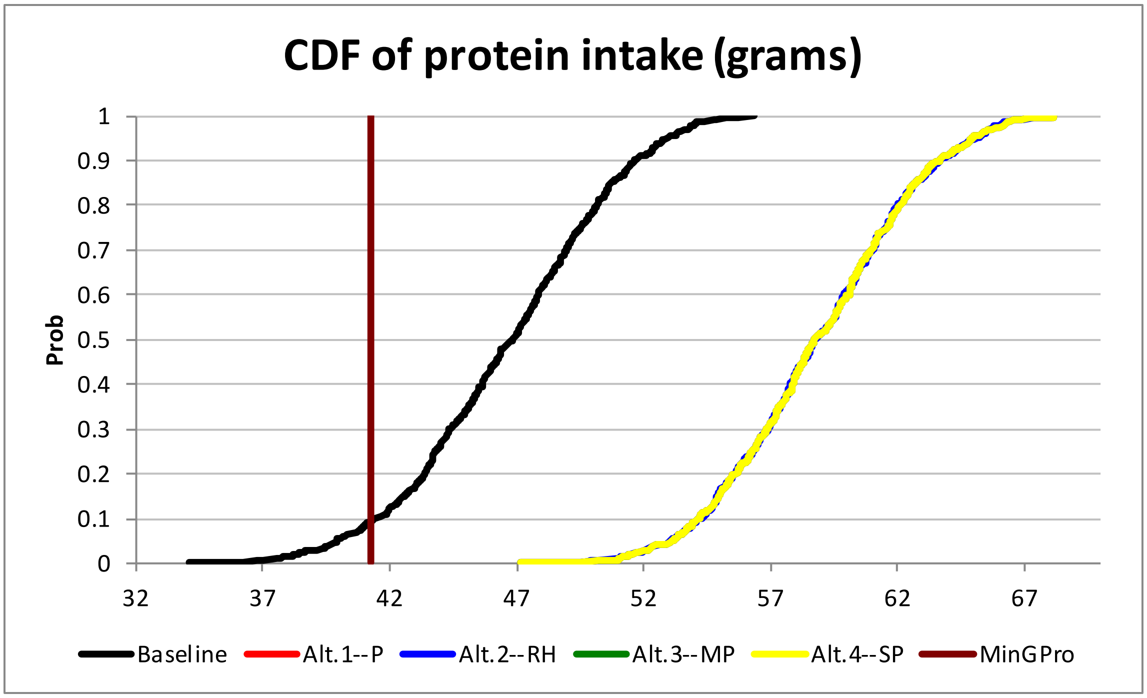


Figure 11a. CDF of daily proteins consumption per AE on a farm in Abirjiha kebele

The StopLight chart for proteins consumption (fig. 11b) indicates that the four alternative scenarios performed significantly better than the baseline scenario in terms of protein intake levels. The simulation results show that the probability that the daily protein intake per AE will be less than the minimum daily requirement of 41 grams is 13% in the baseline scenario, and 0% in the alternative scenarios. Similarly, the chance that daily protein intake per AE will exceed 58 grams is 0% in the baseline scenario and around 57% in the alternative scenarios. However, on average, protein intake in the baseline and alternative scenarios (46 and 58 grams, respectively) are higher than the minimum required amount (41 grams).

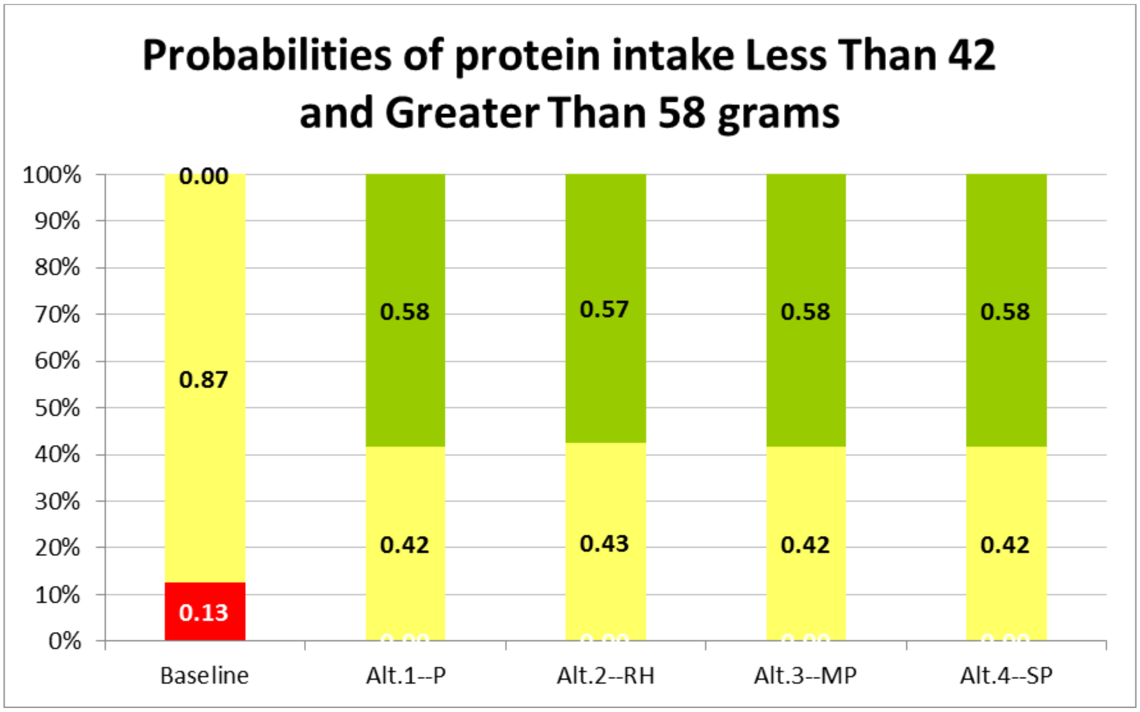


Figure 11b. StopLight Chart for daily proteins consumption per AE on a farm in Abirjiha kebele

c. Fat intake simulation results

Fat along with carbohydrates are the main source of energy, providing the essential amount of calories for the human body to function (Guralnik et al., 2014). However beside that, fat-soluble vitamins such as Vitamin A are easily absorbed by the body with a balanced dietary fat (Global Hunger Index 2014).

Simulation results for fat in Abirjiha kebele, presented as a CDF graph (fig. 12a), 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, 16 and 20 grams, are still below the average minimum fat requirement for an adult (39 grams).

The StopLight chart for fat (fig. 12b) indicates a 32% probability that the fat intake per AE will be less than 16 grams, and 4% probability that it will be greater than 20 grams, for the baseline scenario. Alternatively, there is a 1% probability that the fat intake per AE will be less than 16 grams, and 44% chance it will be greater than 20 grams, for the four alternative scenarios. As noted, results under both the baseline and alternative scenarios fall well short of the minimum fat intake required quantity for an AE.

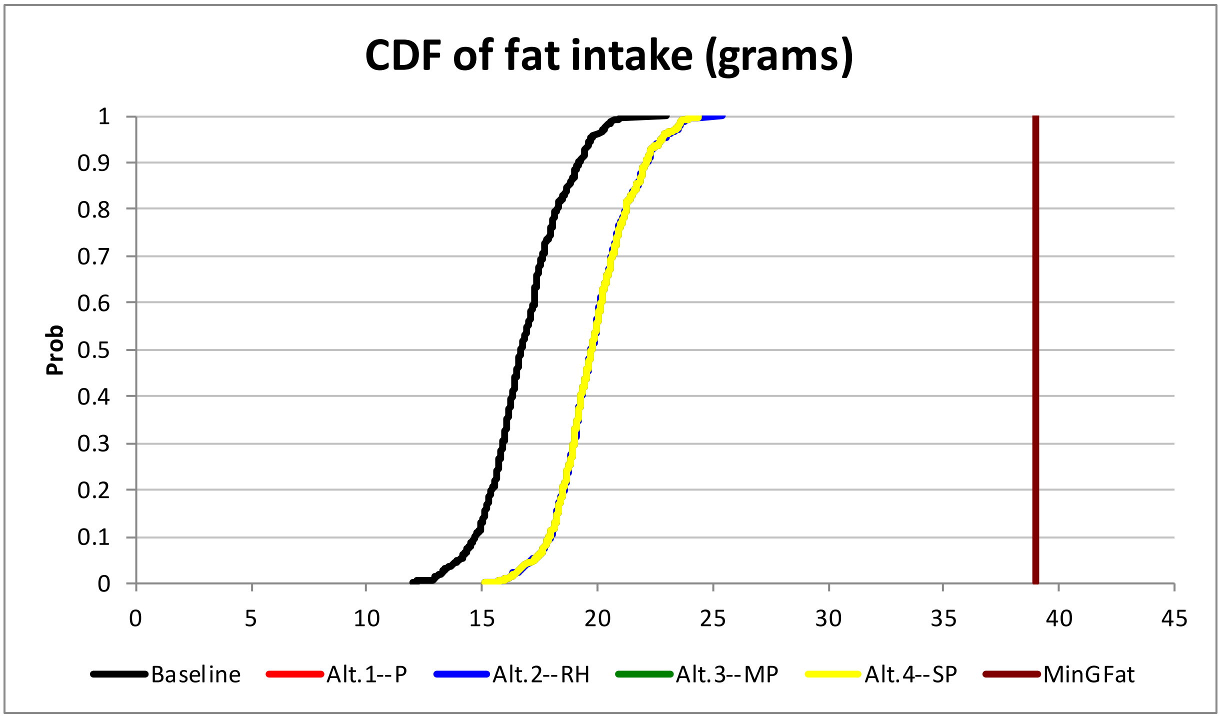


Figure 12a. CDF of daily fat consumption per AE on a farm in Abirjiha kebele

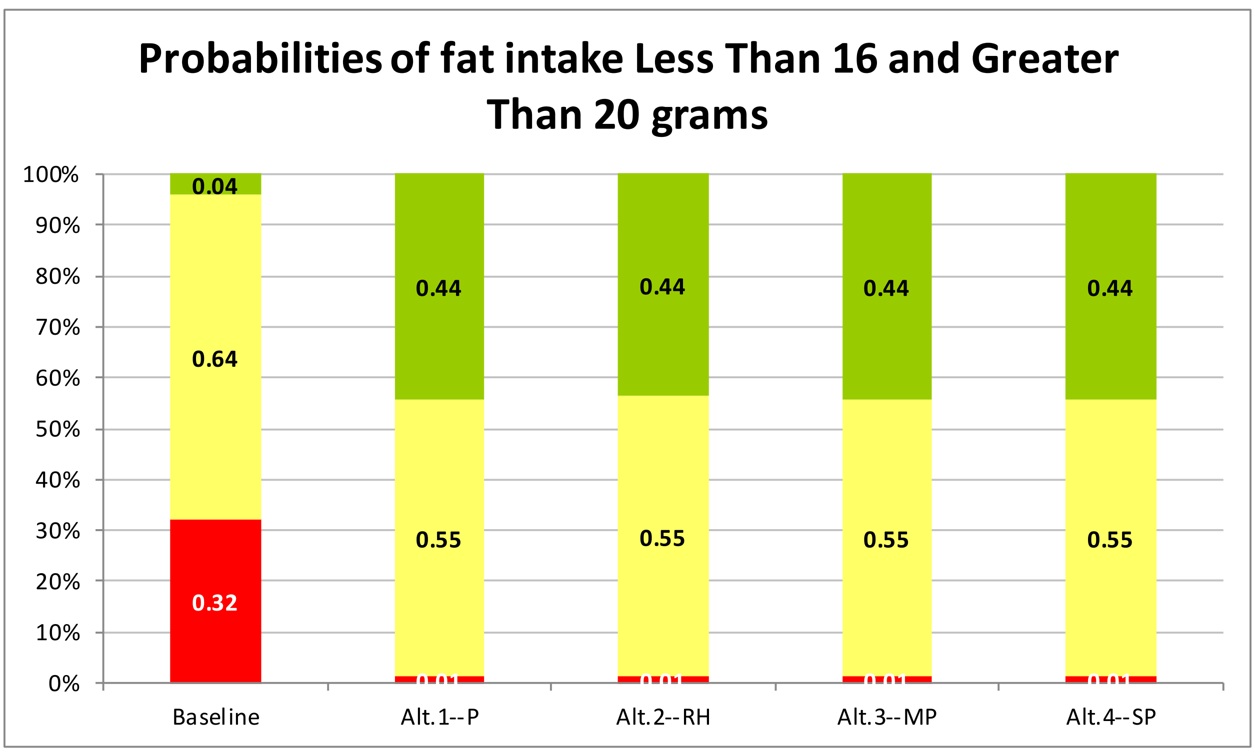


Figure 12b. StopLight Chart for daily fat consumption per AE on a farm in Abirjiha kebele

d. Calcium intake simulation results

The simulation results for calcium (figs. 13a and 13b) show large deficits in calcium intake in both the baseline and alternative scenarios. The average calcium intake per AE is around 0.24 and 0.37 grams respectively for the baseline and four alternative scenarios, falling short to the daily minimum requirements of 1 gram per AE (fig. 13a). Note however the significant improvement of calcium intake from the baseline to the alternative scenarios.

The StopLight chart in figure 13b shows that there is a 52% probability that the daily calcium intake per AE will be less than 0.24 grams and a 0% the intake will exceed 0.37 grams for the baseline. Alternatively, there is a 0% probability that the calcium intake amount will be less than 0.24 grams and 52% chance the intake will exceed 0.37 grams for the four alternative scenarios.

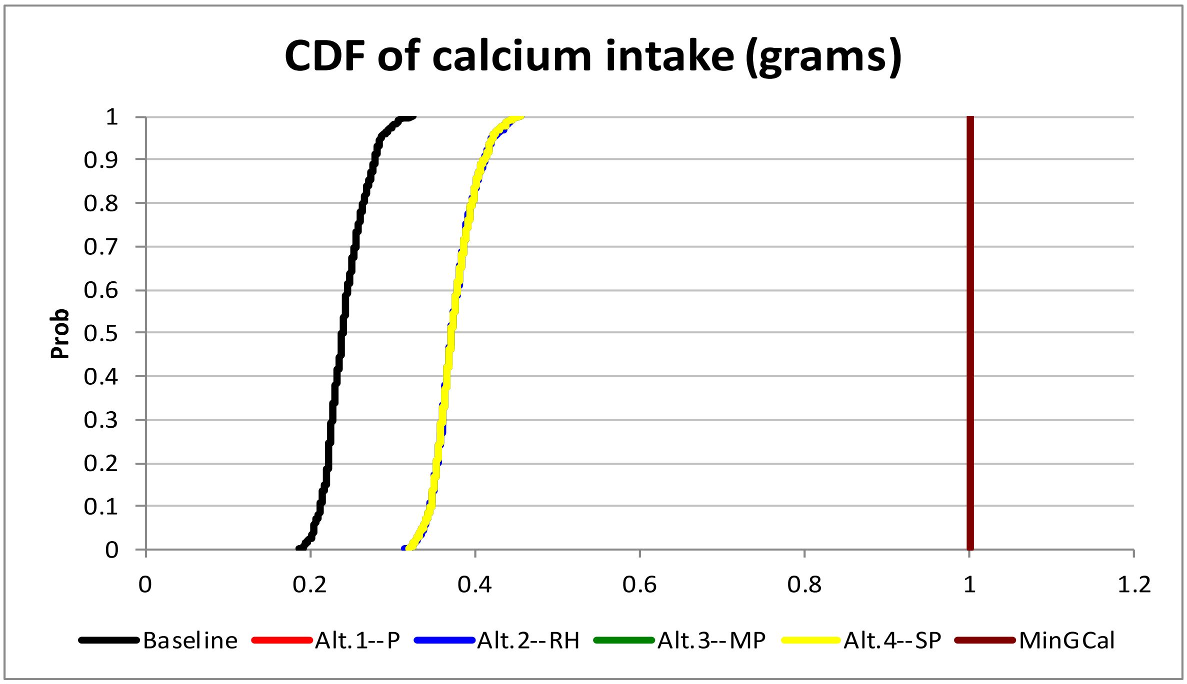


Figure 13a. CDF of daily calcium consumption per AE on a farm in Abirjiha kebele

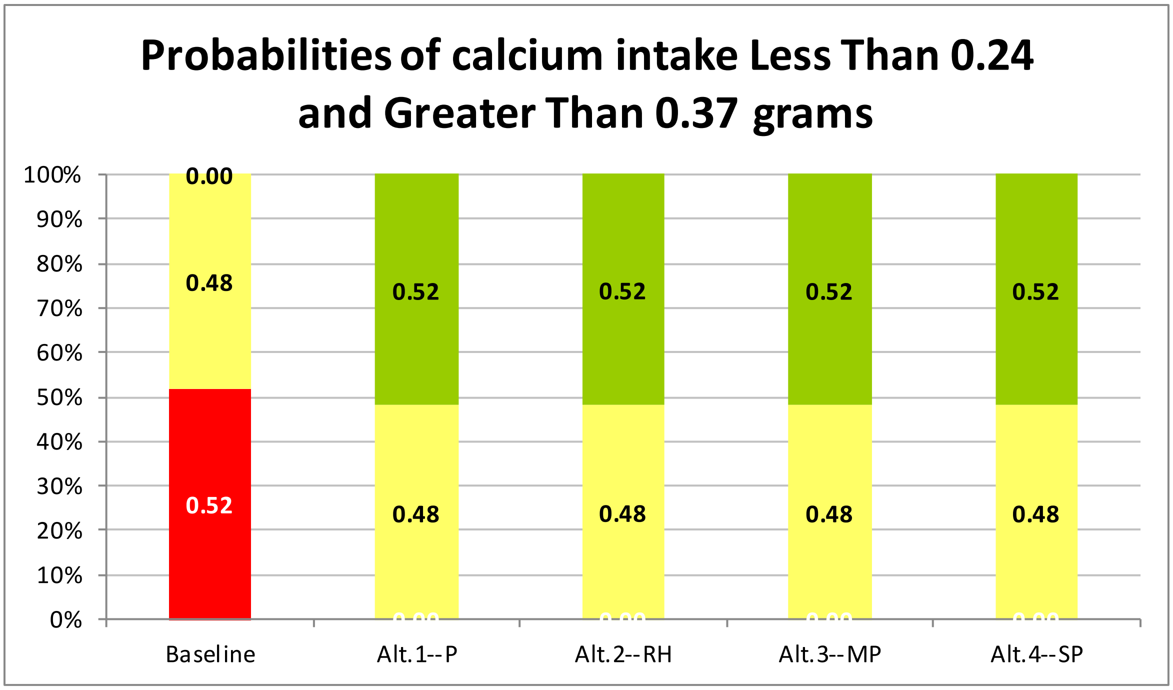


Figure 13b. StopLight Chart for daily calcium consumption per AE on a farm in Abirjiha kebele

e. Iron intake simulation results

The consumption of micronutrients like iron, zinc, vitamin A, and iodine is important for human health and well-being (Global Hunger Index 2014), aiding in the absorption of other nutrients and in child development. Iron deficiency, specifically, is a risk factor for maternal mortality and causes anemia in mothers and children (Domenech 2015).

Simulation results indicated that households in Abirjiha kebele consume more than adequate levels of iron. The average iron intake per AE for all scenarios, estimated at 0.020 grams (or 20 mg), was two times greater than the daily minimum requirement of 0.009 grams (or 9 mg) per AE (fig. 14a). There was also a significant improvement between the baseline and the alternative scenarios in terms of iron intake (averaging 0.17 and 0.24 grams, respectively).

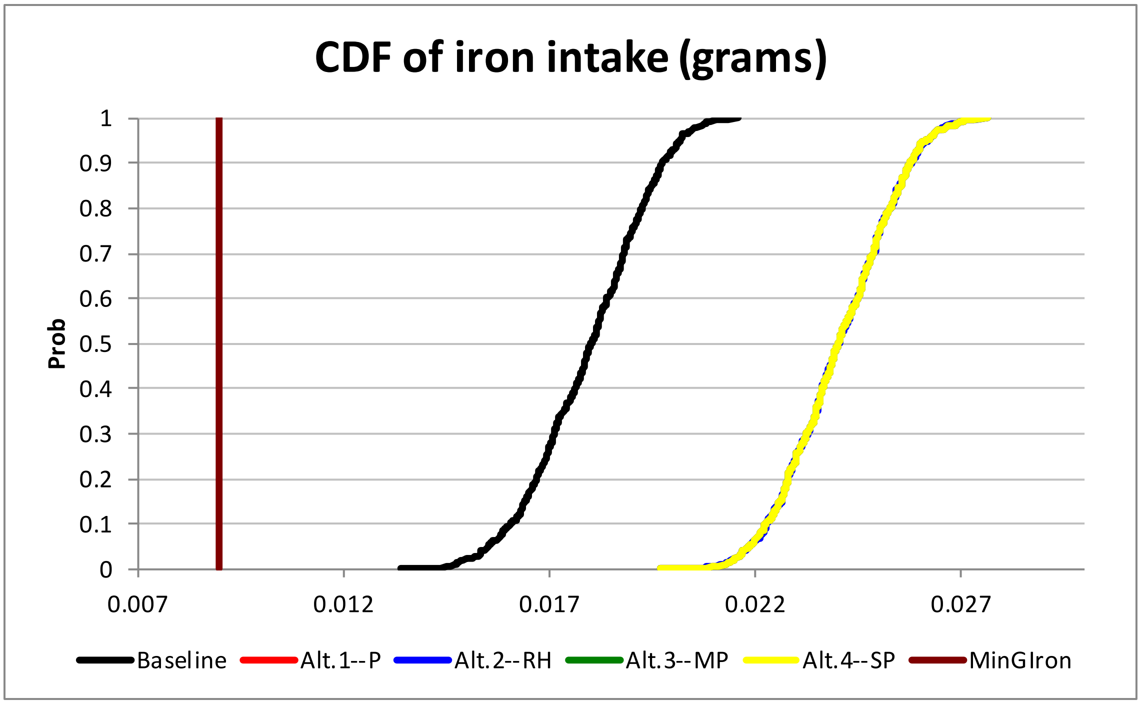


Figure 14a. CDF of daily iron consumption per AE on a farm in Abirjiha kebele

The StopLight chart for iron intake (fig. 14b) indicates that the four alternative scenarios perform significantly better than the baseline scenario in terms of iron availability. In the baseline scenario, there is a 27% probability that the daily iron intake per AE will be less than 0.017 grams and 0% chance that the daily iron intake will be greater than 0.024 grams. Alternatively, in the alternative scenarios, there is 51% chance that the daily iron intake per AE will exceed 0.024 grams and a 0% chance that daily iron intake will be less than 0.017 grams. The target values (0.017 and 0.024 grams, respectively) are the averages of the baseline and alternative scenarios in 500 simulation iterations.

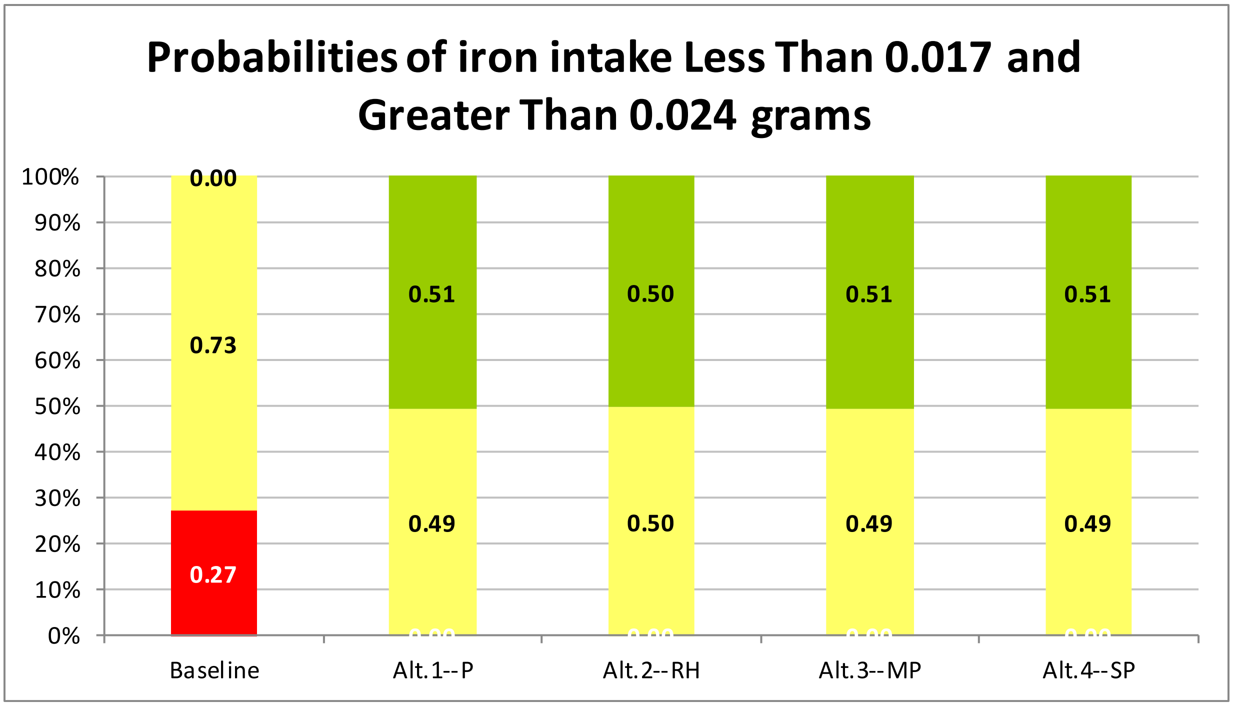


Figure 14b. StopLight Chart for daily iron consumption per AE on a farm in Abirjiha kebele

f. Vitamin A intake simulation results

Like iron, iodine, and zinc, vitamin A is an important micronutrient. Vitamin A is essential for healthy vision and plays a vital role in bone growth, reproduction and a healthy immune system.

The simulation results for vitamin A intake, as set forth in figures 15 a & b, indicate severe deficiencies in vitamin A intake in both the baseline and alternative scenarios. The average vitamin A intake, in all five scenarios, of 2.3E-05 grams (0.000023 grams) is 25 times lower than the minimum daily requirement of 6.0E-04 grams (0.0006 grams) per AE (fig. 15a).

The stop light chart in figure 15b shows that there is an 62% probability that the daily vitamin A intake per AE will be less than 2.24E-05 grams (baseline average), while there is a 0% probability that the vitamin A intake will be greater than 6.0E-04 grams (the minimum requirement for an adult) for the baseline scenario. Likewise, for the alternative scenarios, there is 0% chance that the vitamin A intake will be greater than the minimum requirement for an adult. Note that there is between 38 and 48% probability that the vitamin A intake amount will range between the average baseline intake and the minimum required for an adult.

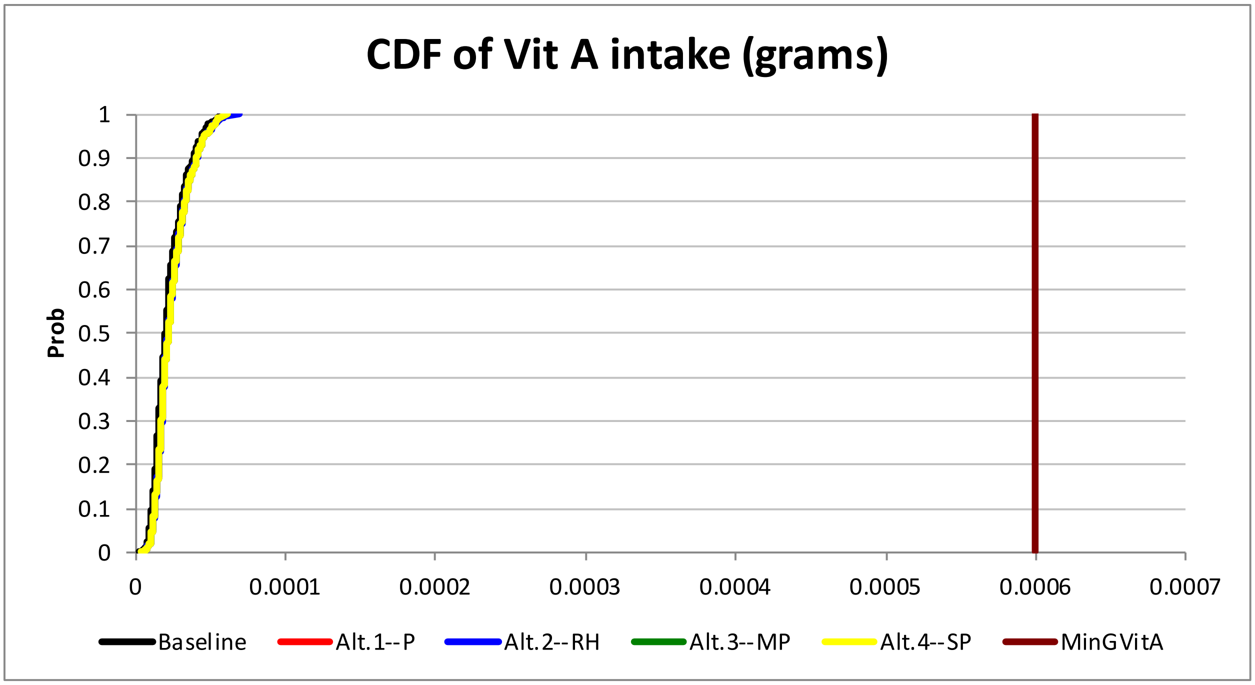


Figure 15a. CDF of daily vitamin A consumption per AE on a farm in Abirjiha kebele

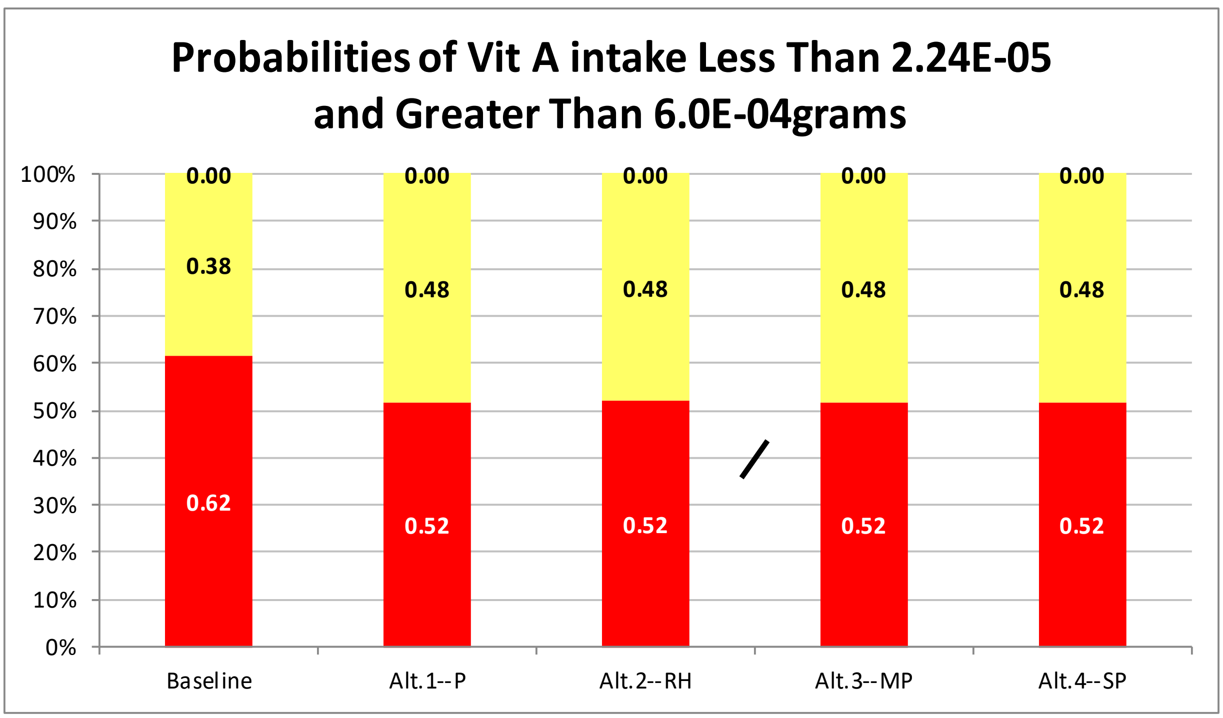


Figure 15b. StopLight Chart for daily vitamin A consumption per AE on a farm in Abirjiha kebele

4.4.5 Ranking of alternative farming technologies

Choosing among risky alternatives can be difficult. Decision makers rank risky alternatives based on their utility for income and risk. Many ranking procedures do not take into account utility (e.g., mean, standard deviation, PDF, CDFs, and coefficient of variation), but the best approaches use utility to rank scenarios. SIMETAR contains several functions to rank risky alternatives, with some of them using a utility function such as 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 we use SERF to identify the preferred risky alternatives given its many advantages over the others. Hardaker, Richardson, Lien and Schuman (2004) created SERF method for ranking risky alternatives by merging CE and Meyer's range of risk aversion coefficients. 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 vary from LRAC = 0 (risk neutral) to URAC = 1 (risk averse), allowing us to evaluate the effects of different levels of risk aversion by decision makers. In ranking the risky alternatives, the SERF approach chooses as the most preferred the scenario with the highest CE at the decision maker's assumed RAC.

In this study, all five scenarios (the baseline and four alternative scenarios) were ranked based on the year 3 simulation results of NCFI. Results in figure 16 show that the motor pump scenario (Alt. 3) is the most preferred scenario. The next most preferred scenarios are the rope-and-washer and solar pump scenarios (Alts. 2 and 4). In the figure below all the scenarios functions seem to decrease as we assume an increasing risk aversion level of the decision maker from risk neutral (LRAC=0) to risk averse (URAC=0.001). Some of the alternative scenarios, such as the rope-and-washer pump scenario (Alt. 2) decrease at a faster rate than the others, which may imply that the decision maker would be willing to take less payoff cash in such a scenario to avoid or shield against risk. Notice that the pulley scenario takes over the rope-and-washer pump scenario at an ARAC of 0.0004 to become the third best preferred scenario.

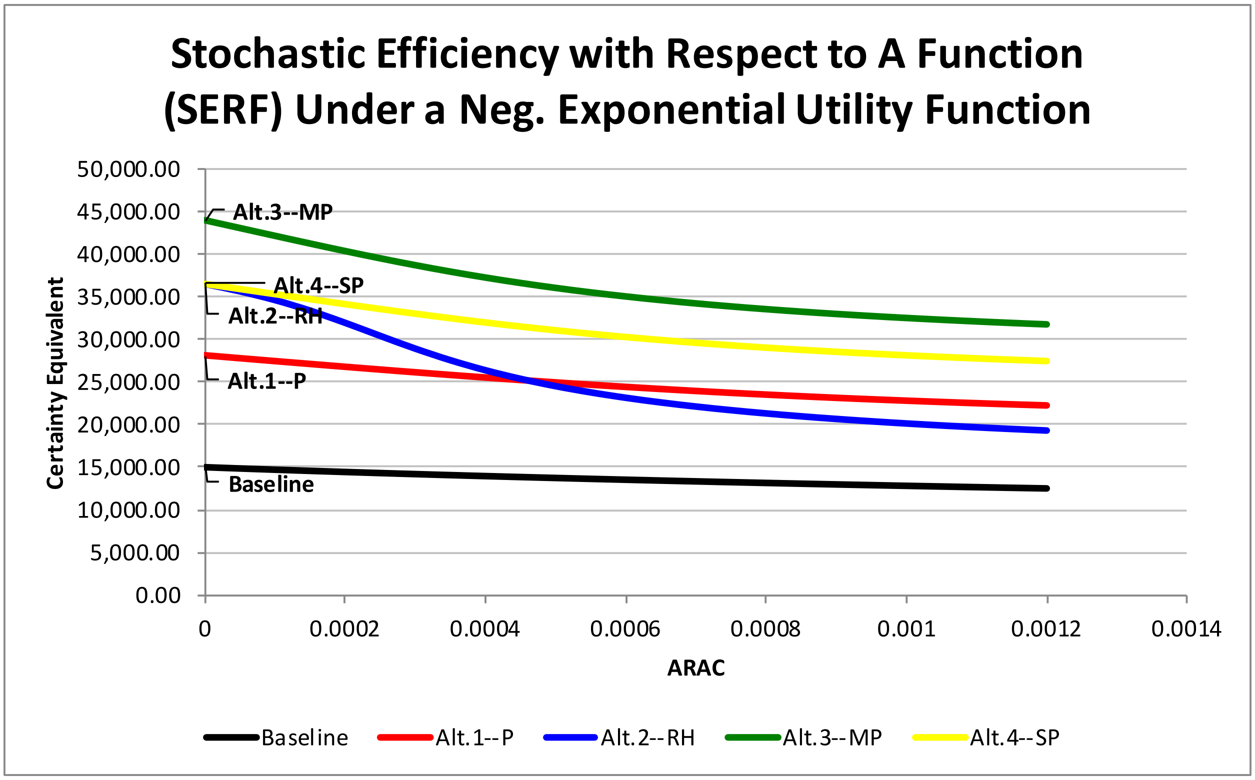


Figure 16. SERF ranking of alternative farming systems in Abirjiha kebele, Dembiya

5. Conclusions

The objective of this study was to evaluate the economic and nutritional impacts of adopting agricultural technologies, including irrigation and recommended fertilization, on farms in Dembiya woreda. The baseline scenario (current fertilizer application rates and irrigation) was compared to four alternative scenarios where recommended fertilizers rates were applied to certain grain and vegetable crops, and irrigated tomato and fodder crops were cultivated during the dry season using one of four alternative water-lifting technologies.

Because comprehensive biophysical and watershed data was not available for Dembiya, this study used data and IDSS simulation results from the nearby BDZ woreda (which is located just 60 km from Dembiya and shares similar rainfall patterns and soil properties) to analyze water availability, potential irrigable land, and crop yields in Dembiya. IDSS simulations of BDZ's Robit watershed indicated that there is large potential for additional SSI in the watershed, and that proposed SSI interventions could be sustained by the shallow groundwater recharge without affecting long-term groundwater storage or, in most respects, the environmental health of the watershed. Simulations of fodder, Napier grass, and alfalfa production n Dembiya, using current agricultural management practices (fertilizers, crop rotation, and irrigation), indicated that fodder yield is limited by nitrogen (with 22 nitrogen stress days per season) and temperature stress (with 3.8 temperature stress days per season). Napier grass yield is limited by temperature, water, and especially nitrogen stress (with 138 nitrogen stress days annually), and alfalfa yield is limited by water and temperature stress.

Economic analyses were conducted to estimate the effects of the proposed SSI interventions (in conjunction with the simulated, improved cropping system) on farm family economics in Abirjiha, a kebele in Dembiya. These simulations also compared the costs and benefits of four alternative water-lifting technologies: pulley-and-bucket irrigation, rope-and-washer pump, gasoline-motor pump, and solar-powered pump. In all, five scenarios (including the baseline, non-irrigated scenario) were simulated. Of the technologies examined, only the gasoline-motor pump met the irrigation water requirements for the proposed SSI interventions (i.e., for all 787 ha of irrigable land in the kebele). The gasoline-motor pump scenario generated the highest income and profits, despite high initial investment and capital costs (twice that of a rope-and-washer pump). The next-best performing scenarios used rope-and-washer or solar-pump irrigation. Individual farmers might benefit by spreading the costs of a gasoline-motor pump over more irrigated area (perhaps sharing a motor with other farmers) or by opting to use the less costly rope-and-washer pump.

In each of the alternative scenarios, the increase in farm revenue was due primarily to the sale of surplus irrigated tomatoes and fodder. Averaging results from the three best-performing alternative scenarios (gasoline-motor pump, rope-and-washer pump, and solar-powered pump), forecasted sales of tomatoes and fodder contributed 40% each, of the total crops receipts and 41% and 39%, respectively, of the net cash (profit) for the five-year planning horizon.

Along with improvements in farm-family economics resulting from the proposed SSI interventions, nutritional levels of most of the nutrients improved under the simulated, improved cropping systems, except for vitamin A. We would also, therefore, propose expanding the types of crops irrigated in the dry season to increase family nutrition and net cash income, but only if such crops can be irrigated without causing excessive soil erosion or reduction in environmental benefits.

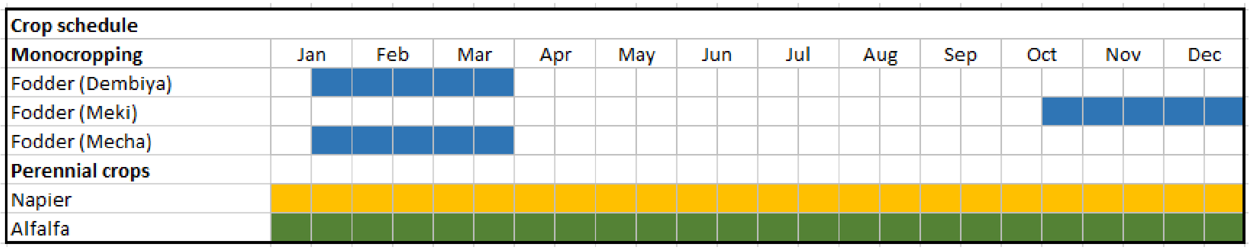
Notably, IDSS simulations of the nearby BDZ woreda revealed very high soil erosion rates. The current and alternative cropping systems simulated for Dembiya, like those simulated for BDZ, could be unsustainable without substantial efforts to reduce soil erosion. Every effort should be made to identify and implement cropping systems that reduce rates of soil erosion. The evaluation of and comparison of alternative farming systems, including the types of crops grown, recommended management practices, and associated impacts on soil erosion and environmental benefits, are subjects for proposed future study.

Appendix A

Ex Ante Analysis of Small-Scale Irrigation Interventions in Robit

Appendix B1

Cropping schedules simulated with APEX



Crop management and fertilization schedules simulated with APEX

(a) Fodder schedule

Operation	Date
Tillage	15-Jan
Tillage	30-Jan
DAP application (50 kg/ha)	30-Jan
Planting	30-Jan
1st stage urea application (25 kg/ha)	30-Jan
2nd stage urea application (25 kg/ha)	25-Feb
Harvest	31-Mar

(b) Alfalfa schedule

Year	Operations	Date	Notes
1st year	Tillage	1/5	
1st year	Tillage	1/20	
1st year	DAP fertilizer application	1/20 (100 kg/ha)	At planting
1st year	Planting	1/20	
1st year	1st Cut	7/19	First cut after 6 months
1st year	Cut	9/17	Harvest every 60 days weeks
1st year	Cut	11/16	Harvest every 60 days weeks
2nd year	Cut	1/15	Harvest
2nd year	DAP fertilizer application	1/20 (100 kg/ha)	Once a year every year (second year)
2nd year	Cut	3/15	Harvest
2nd year	Cut	5/14	Harvest
2nd year	Cut	7/13	Harvest
2nd year	Cut	9/11	Harvest
2nd year	Cut	11/10	Harvest
3rd year	Cut	1/9	Harvest
3rd year	DAP fertilizer application	1/20 (100 kg/ha)	Once a year every year (third year)
3rd year	Cut	3/10	Harvest
		Successive cut every 6 weeks	
4th year	DAP fertilizer application	1/20 (100 kg/ha)	Once a year every year (forth year)
4th year	Cut	3/5	Harvest
		Successive cut every 60 days	
5th year	Harvest	12/25	Harvest
5th year	Kill and replant	12/14 After	Kill and replant

(c) Napier grass schedule

Year	Operations	Date	Notes
1st year	Tillage	1/1	
1st year	Tillage	1/20	
1st year	DAP fertilizer application	1/20 (100 kg/ha)	One time only
1st year	Urea fertilizer application	1/20 (100 kg/ha)	At planting
1st year	Planting	1/20	
1st year	1st Cut	4/20	First cut after 3 months
1st year	Urea fertilizer application	4/21 (100 kg/ha)	After every cut
1st year	Cut	6/19	Harvest every 60 days
1st year	Urea fertilizer application	6/20 (100 kg/ha)	After every cut
1st year	Cut	8/18	Harvest
1st year	Urea fertilizer application	8/19 (100 kg/ha)	After every cut
1st year	Cut	10/17	Harvest
1st year	Urea fertilizer application	10/18 (100 kg/ha)	After every cut
1st year	Cut	12/16	Harvest
1st year	Urea fertilizer application	12/17 (100 kg/ha)	After every cut
2st year	Cut	2/14	Harvest
2st year	Urea fertilizer application	2/15 (100 kg/ha)	After every cut
2st year	Cut	4/14	Harvest
	Successive cut every 60 days and 100 kg/ha urea will be applied next day		
3rd year	Harvest	12/5	Harvest
3rd year	Kill and replant	12/6	Kill and replant

Appendix B2

Current and recommended annual application rates simulated with FARMSIM

Crops \ Fertilizer	Urea (Kgs/ha)		DAP (Kgs/ha)	
	Current	Recommended	Current	Recommended
Teff	22	100	52.1	100
Maize	45.2	100	47.3	100
Sorghum	0*	100**	0	100
Chick peas	0	-	25.6	-
Tomato	0***	200****	0***	200****
Fodder	0	100	0	100
Napier grass	0	100	0	100

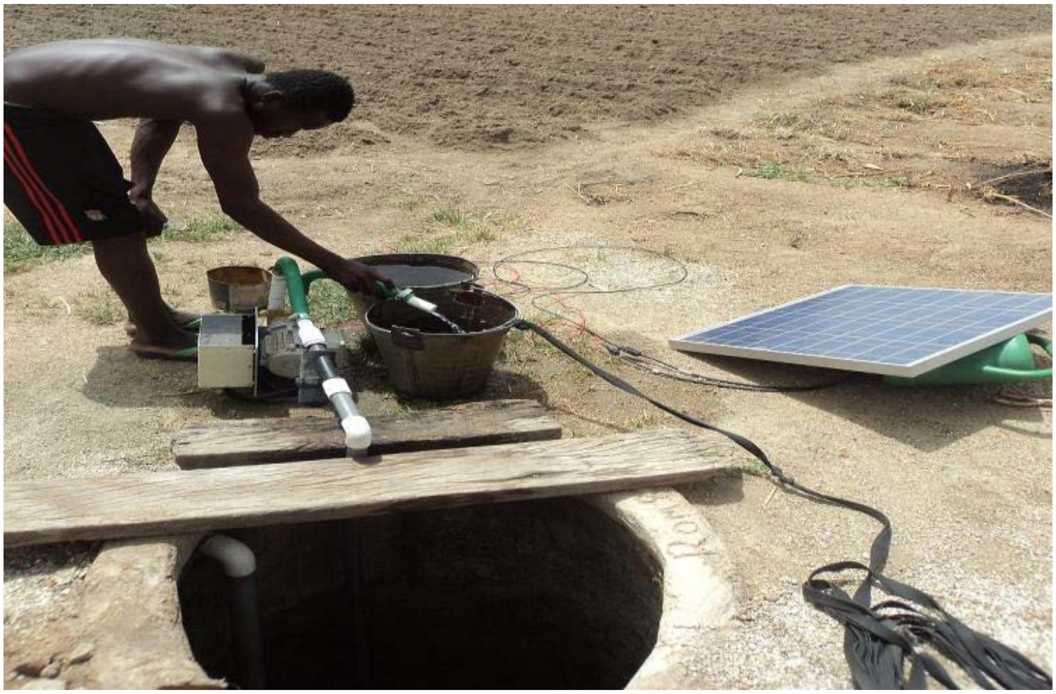
*: fertilizer rates for sorghum are normally low (6kgs/ha) from Minot and Sawyer (2013)
**: recommended rates for sorghum drawn from Endale, K. (2011)
***: the survey and literature do not show application of fertilizer for tomato in Ethiopia
****: recommended fertilizer rates drawn from a study by Etissa et al. (2013)

Appendix C

Water-lifting tools

Pulley/Bucket system (Bahir Dar, Ethiopia)

Motor pump drawing water from river (Bochesa, Ethiopia)



Solar pump installed in Ghana. (Source: Bern University of Applied Sciences, 2013)

Solar pump in rice field in Rangpur, Bangladesh. (Source: Imoberdorf, K. MSc thesis, 2012)

Prototype of a small-scale solar pump developed by BUAS (Rangpur, Bangladesh).
(Source: Imoberdorf, K. MSc thesis, 2012)

Service provider transporting solar pump (Source: Bern University of Applied Science, 2013)

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