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Ex Ante Economic and Nutrition Analysis of Alternative Small Scale Irrigation Systems in Abirjiha Kebele, Dembia Woreda, Amhara Region of Ethiopia

Texas A&M University Integrated Decision Support System Team
USAID Feed the Future Innovation Laboratory for Small-Scale Irrigation

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Introduction

Abirjiha Dihano Wawa kebele (or Abirjiha kebele) is located in the Dembia woreda of the North Gondar zone, in the Amhara region of Ethiopia, on the shores of Lake Tana (figure 1). As of the 2007 Ethiopia Census, a total of 9492 people in 1996 households lived in the kebele. A household and community survey[1] conducted in 2014 by the LIVES project (Livestock and Irrigation Value Chains for Ethiopian Smallholders) (see Gebremedin et al. 2015) reported approximately 11270 people in 1725 households living in the kebele.

The predominant production system in the area is mixed crop and livestock production. 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 given the large amount of ground water existing around the lake Tana area (Assefa, 2015; Ewnetie, 2015). Local households keep cattle, small ruminants (goats and sheep), and poultry (chickens). Farmers raise cattle to meet draught power requirements, while producing milk, meat and butter and breeding stock for income. The majority of milk produced is retained for home consumption, with some milk being processed into butter for sale and family consumption.

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). The LIVES survey also indicated that levels of agricultural and livestock inputs (e.g., improved seeds, fertilizers, irrigation, and animal breed improvements) in Dembia woreda generally— and Abirjiha kebele in particular—are low. Although Dembia has a larger area under irrigation than Lay Armachoho and Gondar Zuria, the two other districts selected for evaluation in the LIVES project (Berhe 2013), the 2014 LIVES survey indicated that only 7% of households in Abirjiha kebele irrigate fruits and vegetables. Only one out of 48 Dembia households surveyed reported owning a motor pump. Also, the level of farm labor hired for agricultural production is 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.
This study was possible through a collaboration between the LIVES and ILSSI projects and intends to carry out a farm-level analysis, using the farm simulation model "FARMSIM," to evaluate the economic and nutritional benefits of adopting different agricultural technologies, including irrigation and fertilizer applications in several LIVES research sites including Dembia woreda.

1 For more information on the survey, see this link: https://lives-ethiopia.org/2014/06/06/baseline-surveys/

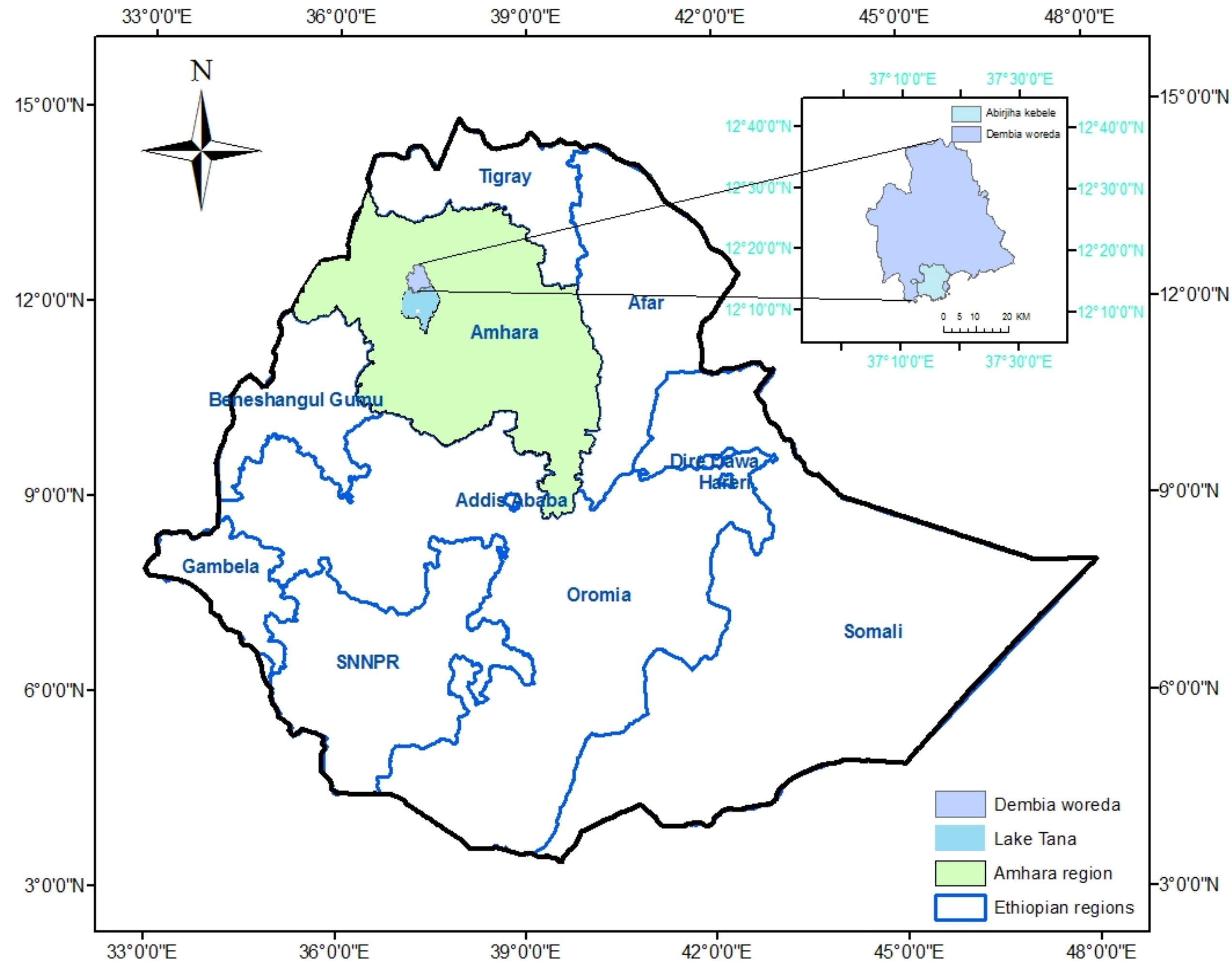

Figure 1. Location of the Abirjiha kebele in Dembia woreda, North Gondar zone

Simulation model

FARMSIM is a Monte Carlo simulation model for quantitatively analyzing the economic and nutritional impacts of alternative farming technologies on small farms in developing countries. The model simulates the current crop and livestock farming system (baseline scenario) and alternative farming systems (alternative scenarios) simultaneously (Clarke et al. 2016, forthcoming). Risk for crop yields, livestock production (e.g., birth rates, death rates, weight gain, and milk production), and market prices is explicitly included in the model so the results can be presented in terms of probabilities. Simetar© (Simulation and Econometrics to Analyze Risk) is the simulation engine used to simulate the FARMSIM model. Simetar is a simulation language written for risk analysts to provide a transparent method for analyzing data, simulating the effects of risk and presenting results in the user-friendly environment of Microsoft® Excel. The baseline and alternative scenarios are simulated using the same equations, so that the differences in the economic and family nutrition outcomes are attributable to the differences in technologies.

The FARMSIM model was run 500 times for each of five scenarios—the baseline scenario and four alternate scenarios, described below—to sample variation in crop yields due to weather and other stochastic variables. To determine which of the five scenarios would be most beneficial to farm families, three types of economic indicators or key output variables (KOV) were calculated: net present value (NPV), net cash farm income (NCFI), and ending cash reserves (EC). The performance of the five scenarios as estimated by each of the three indicators was displayed graphically as a cumulative distribution function (CDF) and as a "stoplight graph." Similar simulation procedure is used to determine the impact of the irrigation technology adoption on the nutritional variables that include calories, proteins, fat, calcium, iron and vitamin A.

Data

Farm-level input information for crops and livestock was drawn from a survey conducted by the LIVES project in January 2014. A sample size of about 36 households was considered to summarize farm input information. The primary data were supplemented by secondary data that included expert opinion, research articles, and reports from government and non-government agencies. The survey shows that the major crops grown, by area, in Abirjiha and other surrounding kebeles are maize (221 ha), sorghum (612 ha), teff (991 ha), and chickpea (354 ha) on an estimated total cropland of 2800 ha (rain-fed and irrigated). Irrigated tomato and fodder (vetch & oats) were selected as vegetable and animal feed crops to consider in this study. Due to the lack of crop management and biophysical information, we were not able to include other irrigated crops such as potato, garlic and pepper. Napier grass was as well simulated, not for animal feeding on the farm but as cash crop. Current and recommended fertilizer application rates assumed in the FARMSIM model, and the sources of these data, are set forth in table 1. Two biophysical models, SWAT (Soil and Water Assessment Tool) and APEX (Agricultural Policy/ Environmental eXtender), were used to assess soil, water, and crop growth characteristics at the watershed and field scales, respectively.

Table 1. Current and recommended annual fertilizer rates, Abirjiha kebele

	Urea (Kgs/ha)		DAP (Kgs/ha)	
Crops	Current	Recommended	Current	Recommended
Teff	22	100	52.1	100
Maize	45.2	100	47.3	100
Sorghum	0*	100**	0	100
Chickpeas	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)

Scenario analysis

Baseline scenario

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.

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 all 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. 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 (See pictures in Appendix A).

As compared to the baseline scenario, yield increases were expected for maize and teff as a result of higher fertilizer application rates. With fertilization and dry-season irrigation, yield increases were also expected for tomatoes.

Assessment of water-lifting technologies

In comparing the four water-lifting technologies, we estimated the costs of each technology, as well as the amount of land that could be irrigated by each without water stress to the crops. Our assessment was based on the costs (operating and capital) of each water-lifting technology and the capacity of each to irrigate available land, as determined by its respective pumping rate. Our analysis assumed the following:

1) Number of active family members (adults) required to carry out the irrigation: 2
2) Number of irrigation hours per irrigation day: 1.5
3) Number of irrigation days per season, assuming irrigation every other day for three and a half months (January through mid-April): 65
4) Total number of hours of irrigation per season: 1.5*65 = 97.5 hours/season
5) Pumping rates (L/min) for the different water-lifting technologies:
    - Pulley and bucket: 10 L/min
    - Hand-operated rope-and-washer pump: 15 L/min
    - Motor pump: 170 L/min
    - Solar pump: 16 L/min

   Note: pumping rates were obtained from field data gathered by IWMI on behalf of the ILSSI project.

Crop yields were simulated by APEX at different levels of irrigation water depth for 32 years. The irrigator's equation was used to estimate the total amount of water that can be delivered by a water-lifting technology:

Irrigator's equation: $Q*T = d*A$

Q: flow or pumping rate (L/min)

T: time (min) for irrigation

d: depth of irrigation water applied (mm)

A: area covered (m^2 or ha)

Based on the total amount of water (mm) required to irrigate a crop for the entire dry season and the total amount of water per hectare delivered by each water-lifting technology (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 used that fraction to compute the percentage of cropland that could be irrigated with minimal water stress for each water-lifting technology. Given the water needs in the dry season for irrigated tomato and vetch, only the motor pump was able to provide the required water quantity to tomato and vetch (0% water stress level) for the maximum irrigable land of 787 ha (table 2). The pulley irrigation system covered only 34% of the maximum irrigable land while the rope-and-washer and solar pump irrigation systems covered about 52% and 55% respectively of the maximum irrigable land (table 2).

Table 2. Water-lifting technologies (WLT)

Types of WLT	Operated by	Flow rate (l/min)	Cost WLT (ETB)	Irrig. Land covered (ha)	Constraints
Pulley/bucket	Hand	10	1310	274	labor
Rope & washer pump	Hand	15	3700	411	breakdowns
Motor pump	Fuel	170	8500	787	maintenance
Solar pump	Solar	16	16000	438	capital costs

Note: we did not include the cost of digging wells in our final estimates, since field data collected by IWMI in 2015 indicated that several households already had wells in place

The total irrigable land covered with each irrigation technology, as set forth in table 2 above, determines the total quantity of irrigated crops produced and sold, and consequently the farm revenue. For each irrigation technology, the projected revenues must be weighed against estimated costs. Considering the higher initial investment and operating costs for motor and solar systems, a pulley-and-bucket system or a rope-and-washer pump could be preferred options for an average farmer, supplying enough water to dry-season crops to make the lower investment in irrigation worthwhile.

Results and discussion

The analyses that follow reference the baseline and alternative scenarios 1, 2, 3, and 4 (Alts. 1-4), discussed in some detail above. The baseline 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

The results presented below in the stoplight chart and CDF graphs represent the year 5 simulation results from a 5-year forecasting period except for NCFI whose results are from year three.

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 financial variables (NCFI and EC) and nutrition.

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 3a, 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.

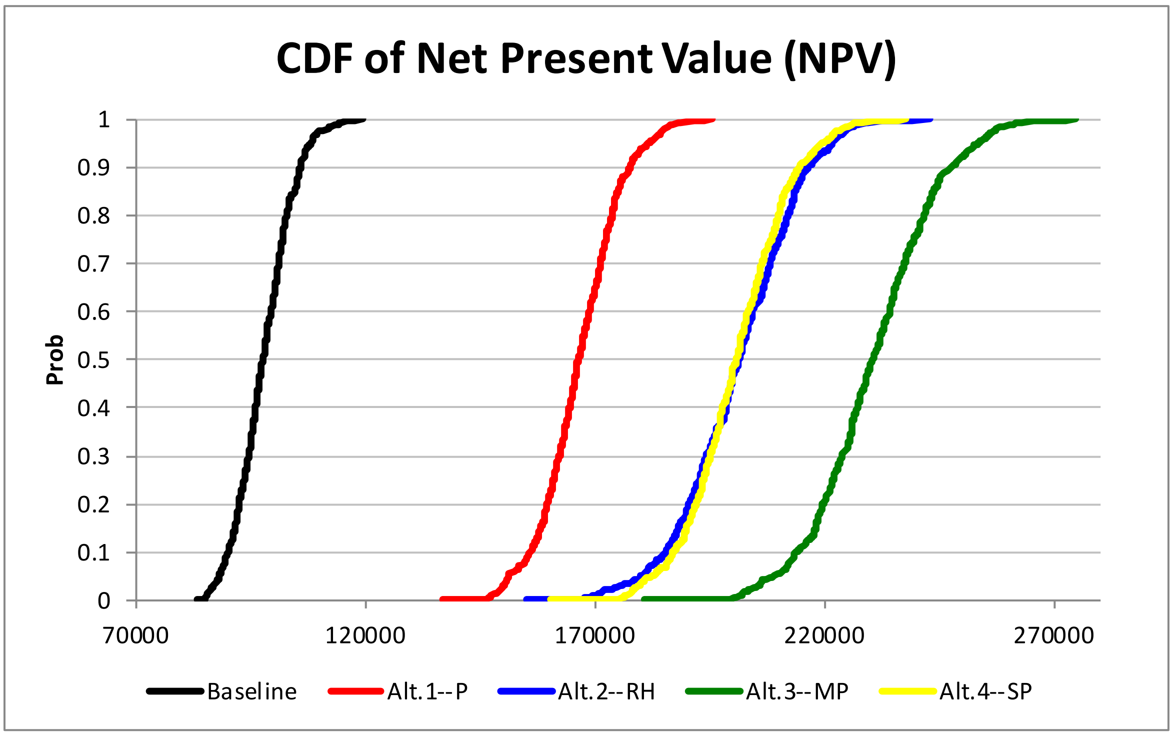

Figure 3a. CDF of NPV for alternative irrigation technologies in Abirjiha kebele, Dembia

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

The stoplight chart below (fig. 3b) presents the probabilities of NPV being less than 100000 ETB (Ethiopian Birr) (red), greater than 214000 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 100000 ETB and a 0% chance that NPV will exceed 214000 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 214000 ETB. In contrast, in the motor pump scenario (Alt. 3), there is a 90% probability that NPV will exceed the upper target of 214000 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.

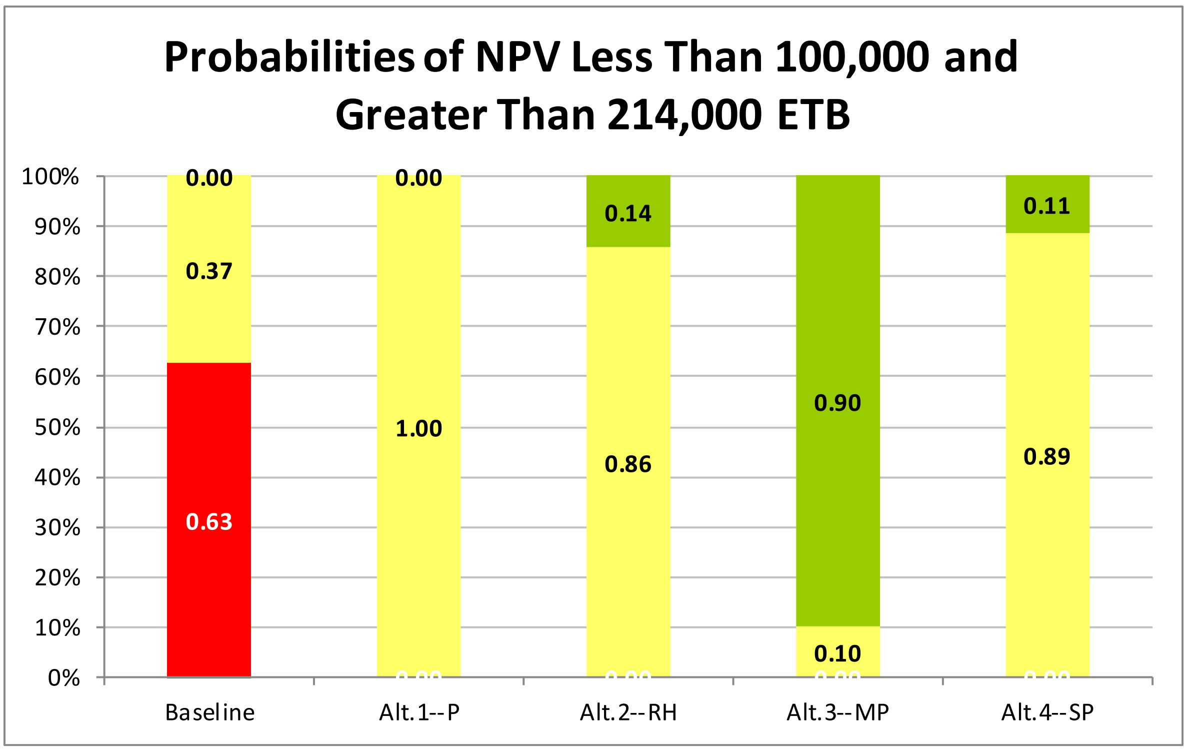

Figure 3b. StopLight chart for per-family NPV in Abirjiha kebele, Dembia

NCFI

Annual NFCI measures the amount of profit generated by the farm for the baseline and alternative scenarios. The simulation results (fig. 4a.) 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.

The stoplight chart for NCFI in year 3 of the 5-year planning horizon (fig. 4b) shows that, for a representative farm in the baseline scenario, there is a 68% probability that NCFI will be less than 16000 ETB and a 0% probability that NCFI will exceed 40000 ETB. In contrast, in the motor pump scenario (Alt. 3), there is a 75% chance that annual NCFI will exceed 40000 ETB and just a 25% probability that NCFI will fall between 16000 and 40000 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 40000 ETB, and a 74% probability that annual NCFI will fall between 16000 and 40000 ETB. The pulley/bucket scenario (Alt. 1), though inferior to the other alternative scenarios, performed better and generated higher profits than the baseline scenario.

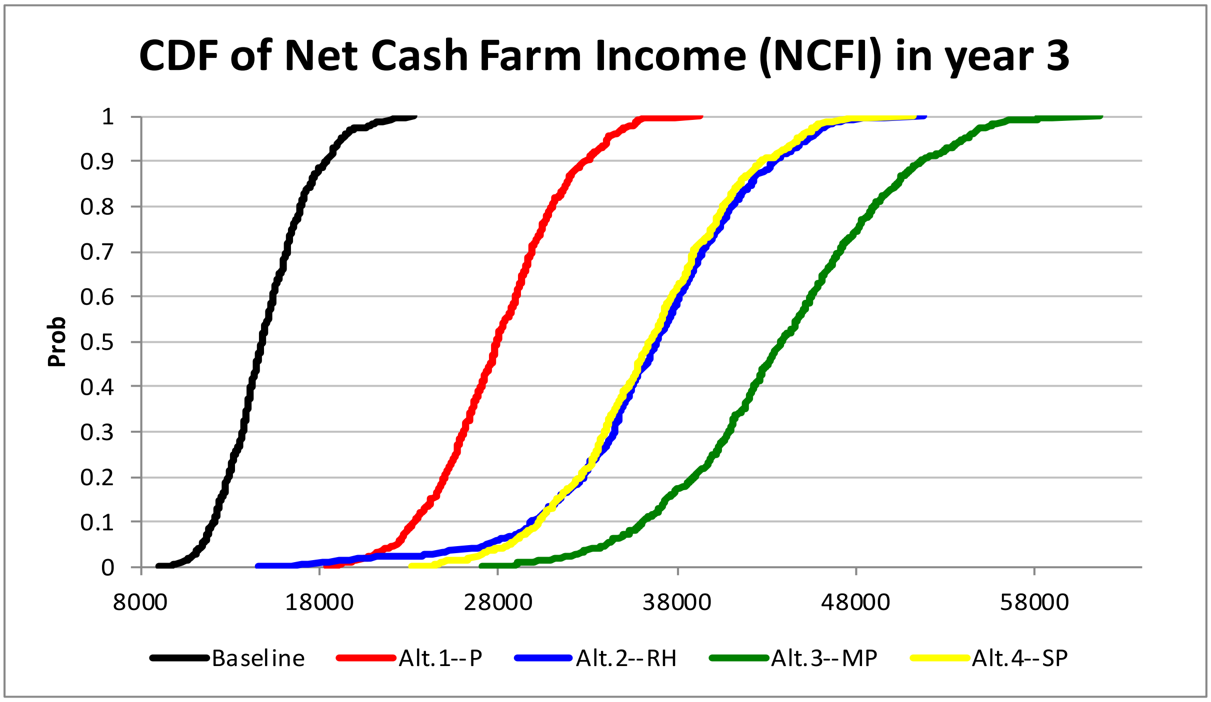

Figure 4a. CDF of NCFI for Abirjiha kebele, Dembia

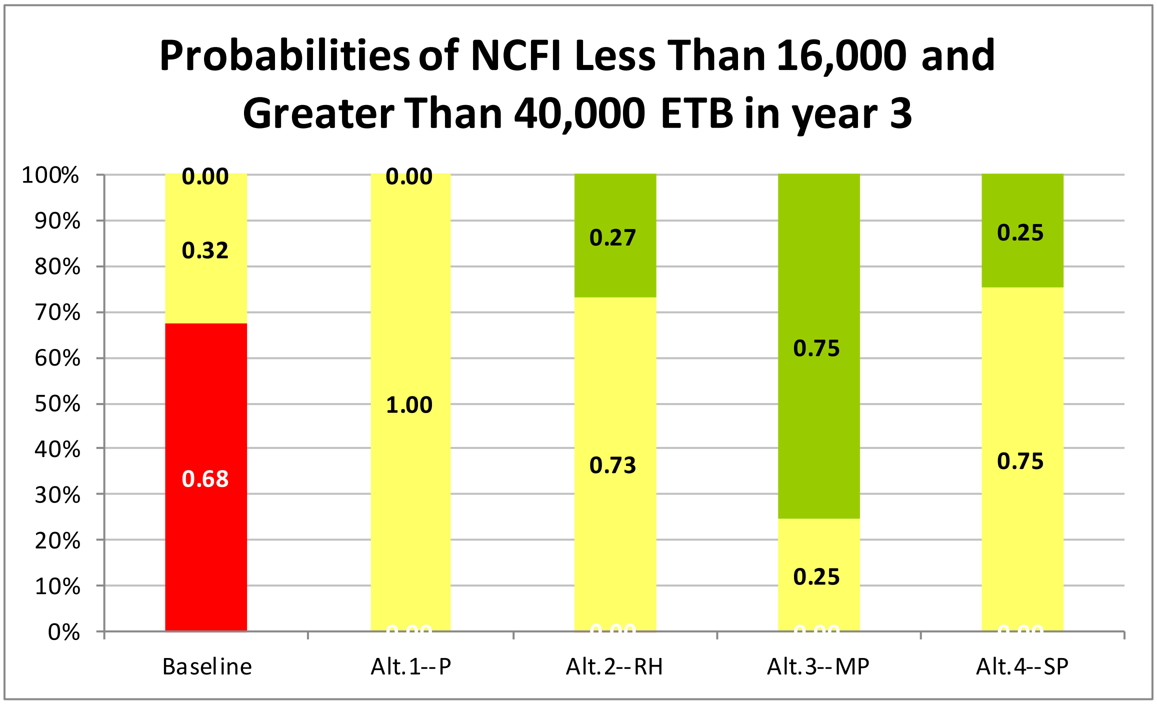

Figure 4b. StopLight chart for per-family NCFI in Abirjiha kebele, Dembia

EC

The EC simulation results (figs. 5a and 5b) 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. 5b) shows that, in the baseline scenario, there is a 52% probability that EC in year 5 will be less than 75000 ETB and a 0% probability that EC will exceed 200000 ETB. Alternatively, in the motor pump scenario, there is a 0% probability that EC will be less than 75000 ETB, and a 92% probability that EC will exceed 200000 ETB. The second best choices are the rope-and-washer and solar pumps scenarios (Alts. 2 and 4, respectively), which have a 10% and 9% chance, respectively, of generating EC greater than 200000 ETB. The pulley/bucket scenario (Alt.1) generates higher EC than the baseline scenario.

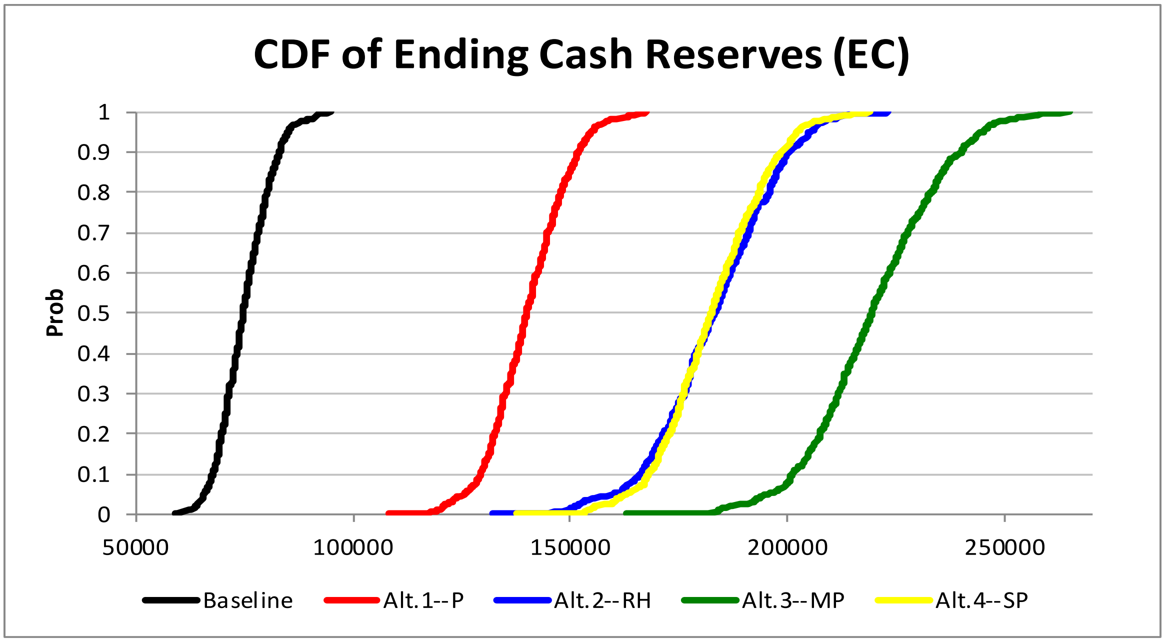

Figure 5a. CDF of EC in Abirjiha kebele, Dembia

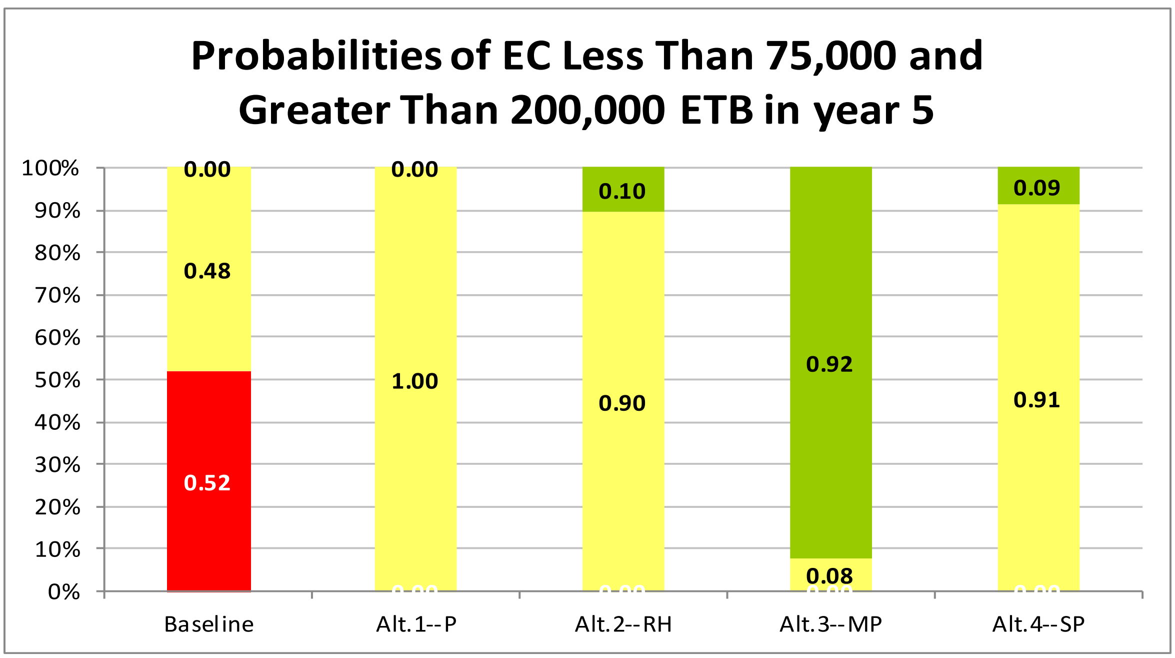

Figure 5b. StopLight chart for per-family EC in Abirjiha kebele, Dembia

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.

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 both the baseline and alternative scenario meet minimum daily requirements for iron and proteins but are insufficient to meet minimum daily requirements for calories, fat, calcium, and vitamin A. 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 3 summarizes simulation results based on the fifth year forecast from the 5-year planning horizon. Specifically, table 3 lists the nutritional variables measured, the probability that the quantity of each nutrient consumed will exceed the minimum daily requirement, and whether the amounts consumed in the alternative scenarios show 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 increased substantially in the alternative scenarios (table 3), probably because of production increase in the alternative scenarios due to technology. 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. More detailed information on minimum requirements are in UN-FAO (2001 a & b) and UN-FAO (2008).

Table 3. Summary results for nutrition and scenario performance

	Performance		
Nutrition variables	Excess or deficit	Probability: nutrients 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.

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. 6a) 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.

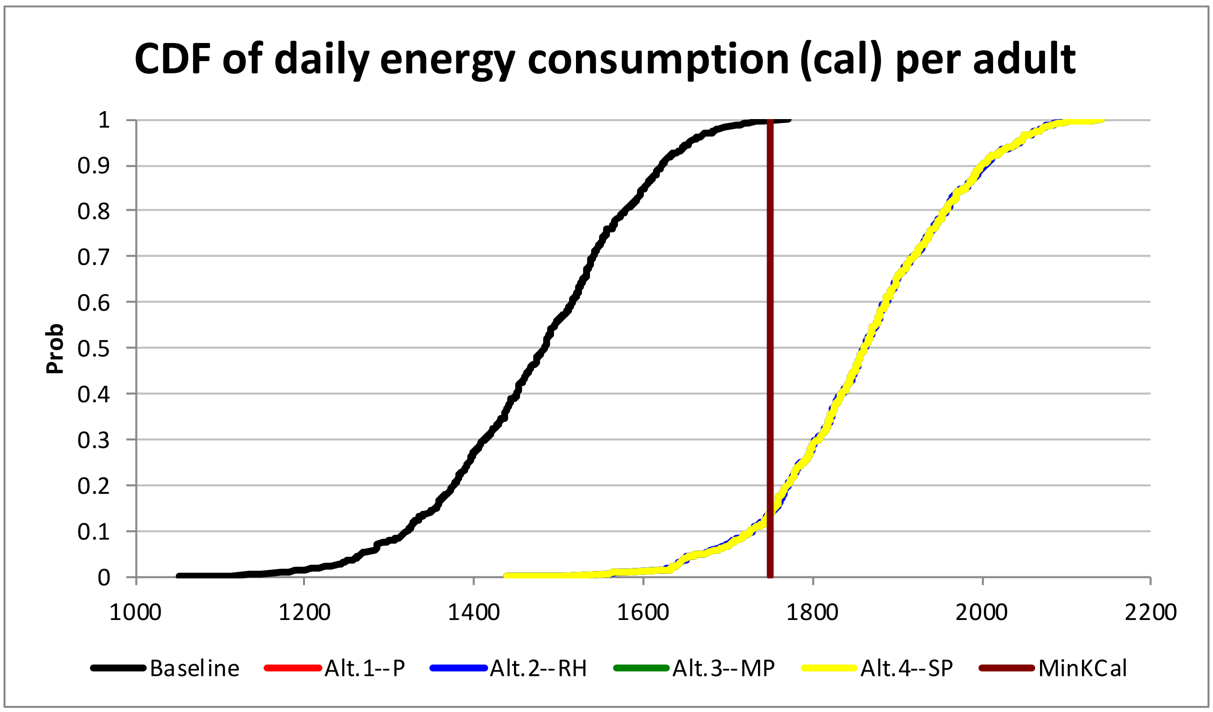

Figure 6a. CDF of daily energy consumption per AE on a farm in Abirjiha kebele

The StopLight chart for daily energy consumption per AE is presented in Figure 6b. 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.

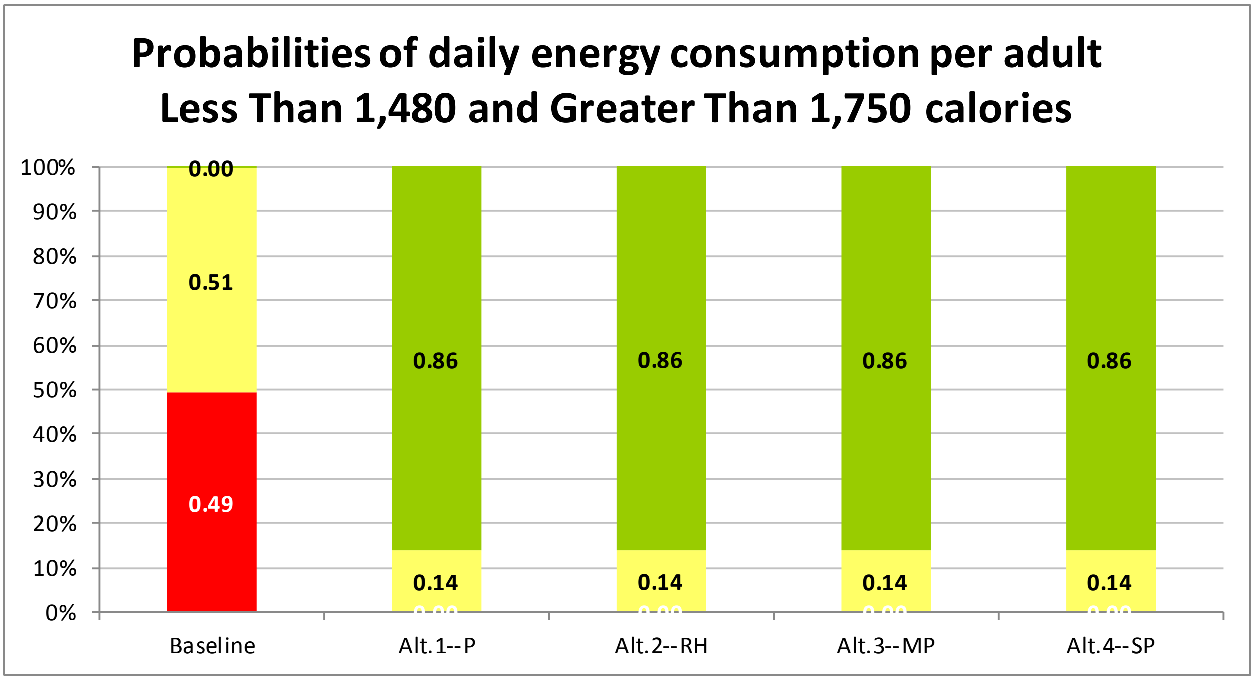

Figure 6b. StopLight Chart for daily energy consumption per AE on a farm in Abirjiha kebele

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 7a, below, show that households in both the baseline and alternative meet the minimum daily requirement for proteins intake (41 gr/AE) at the exception of a small fraction (10%) in the baseline scenario. There was very a clear improvement in the alternative scenarios as compared to the baseline scenario.

The StopLight chart for proteins consumption (fig. 7b) indicates that the four alternative scenario 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, the baseline and alternative scenarios protein intake (46 and 58 grams respectively) are higher than the minimum required amount (41grams)

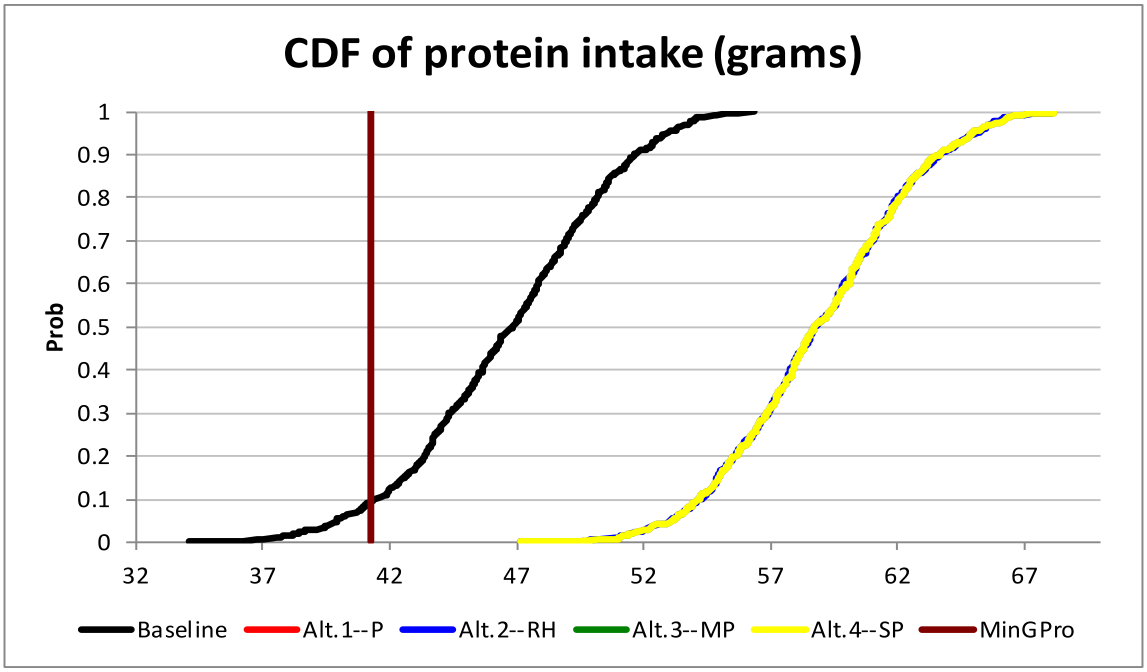

Figure 7a. CDF of daily proteins consumption per AE on a farm in Abirjiha kebele

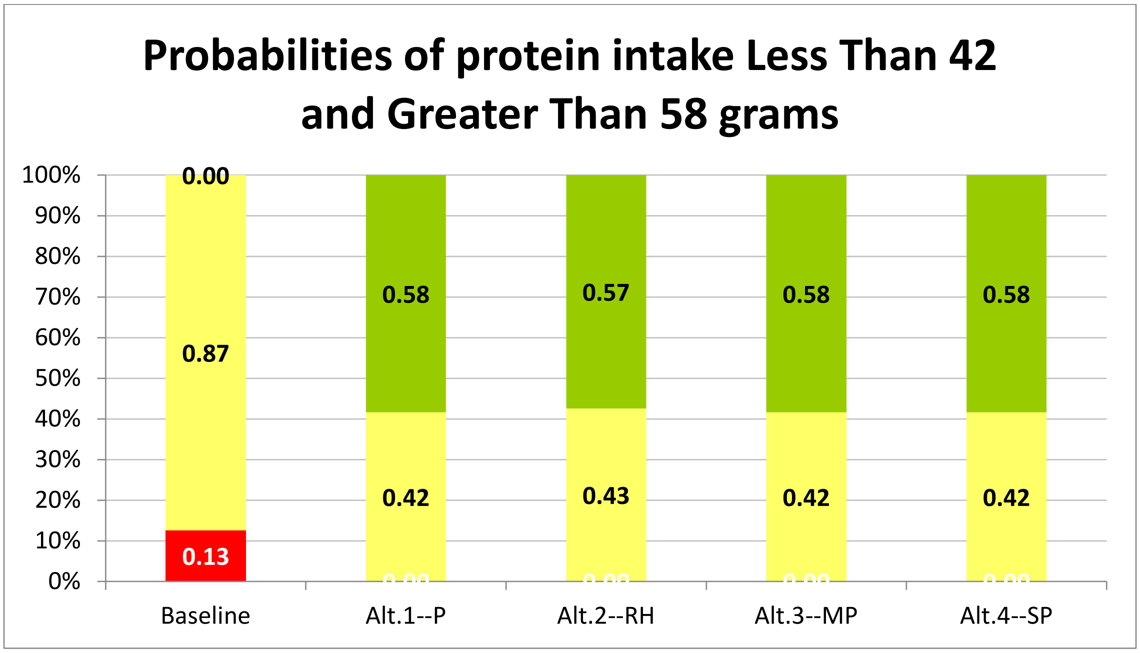

Figure 7b. StopLight Chart for daily proteins consumption per AE on a farm in Abirjiha kebele

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 presented as a CDF graph (fig. 8a) in Abirjiha kebele 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. 8b) 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 noticed both results under the baseline and alternative scenario fall half way short to the minimum fat intake required quantity for an adult equivalent (AE).

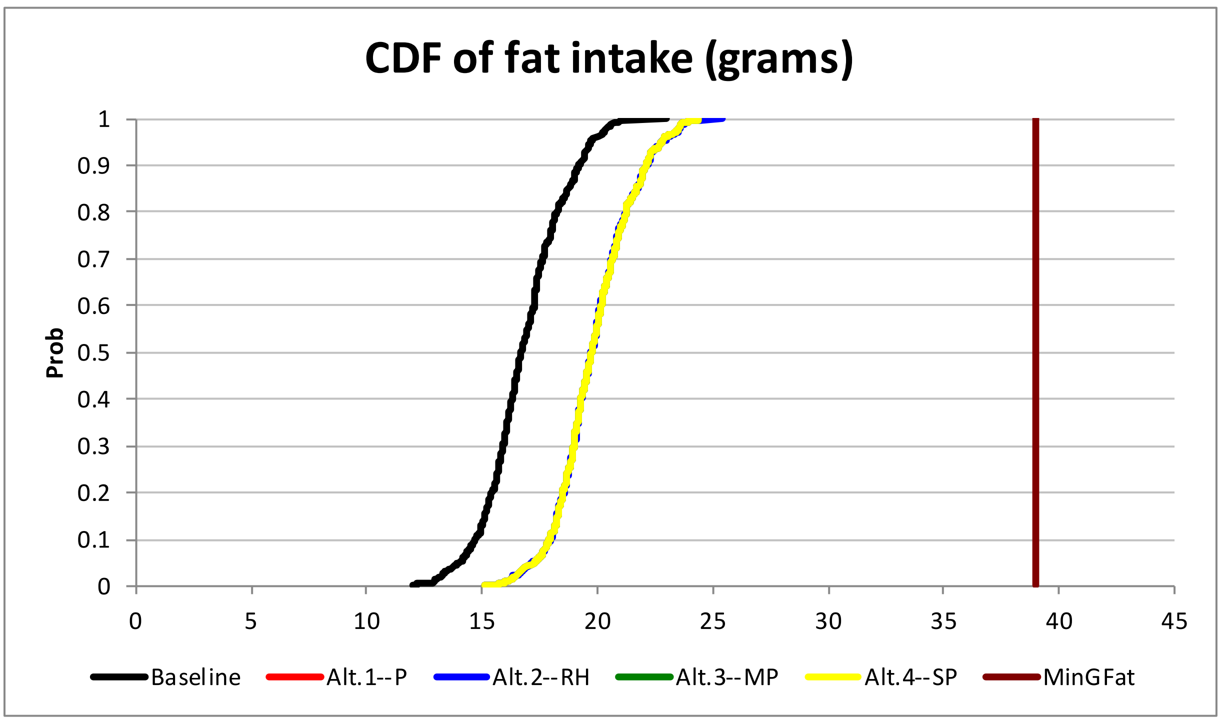

Figure 8a. CDF of daily fat consumption per AE on a farm in Abirjiha kebele

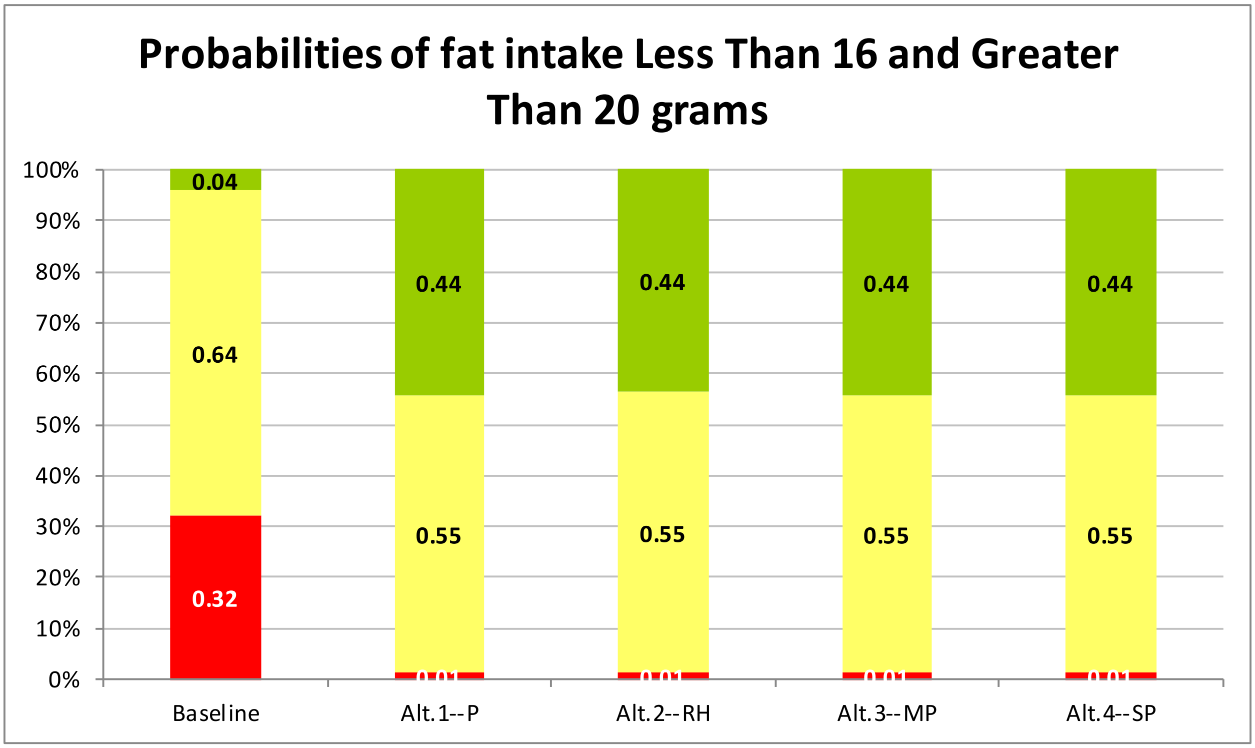

Figure 8b. StopLight Chart for daily fat consumption per AE on a farm in Abirjiha kebele

<u>Calcium intake simulation results</u>

The simulation results for calcium (figs. 9a and 9b) 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 g respectively for the baseline and four alternative scenarios, falling short to the daily minimum requirements of 1 gram per AE (fig. 9a). Note however the significant improvement of calcium intake from the baseline to the alternative scenarios.

The StopLight chart in figure 9b 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. The chart shows as well that there is a 48% probability that the daily calcium intake per AE in Abirjiha kebele will range between 0.24g and 0.37g for the Baseline scenario. Alternatively, there is a 0% probability that the calcium intake amount will be less than 0.24 g and 52% chance the intake will exceed 0.37 g for the four alternative scenarios. However, more simulation results on several scenarios analysis show that there is no chance that the daily intake in calcium per adult equivalent, which currently stands at 0.37g for the best performing scenarios, would reach the minimum requirement of 1g per day and per adult equivalent (AE).

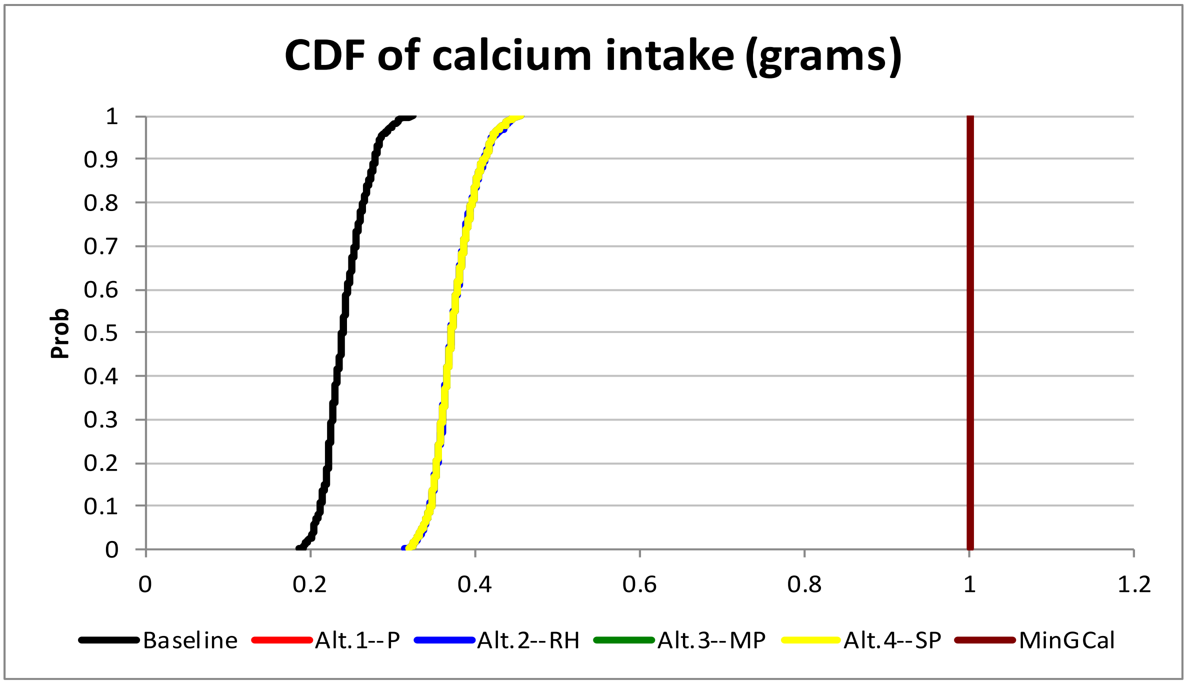

Figure 9a. CDF of daily calcium consumption per AE on a farm in Abirjiha kebele

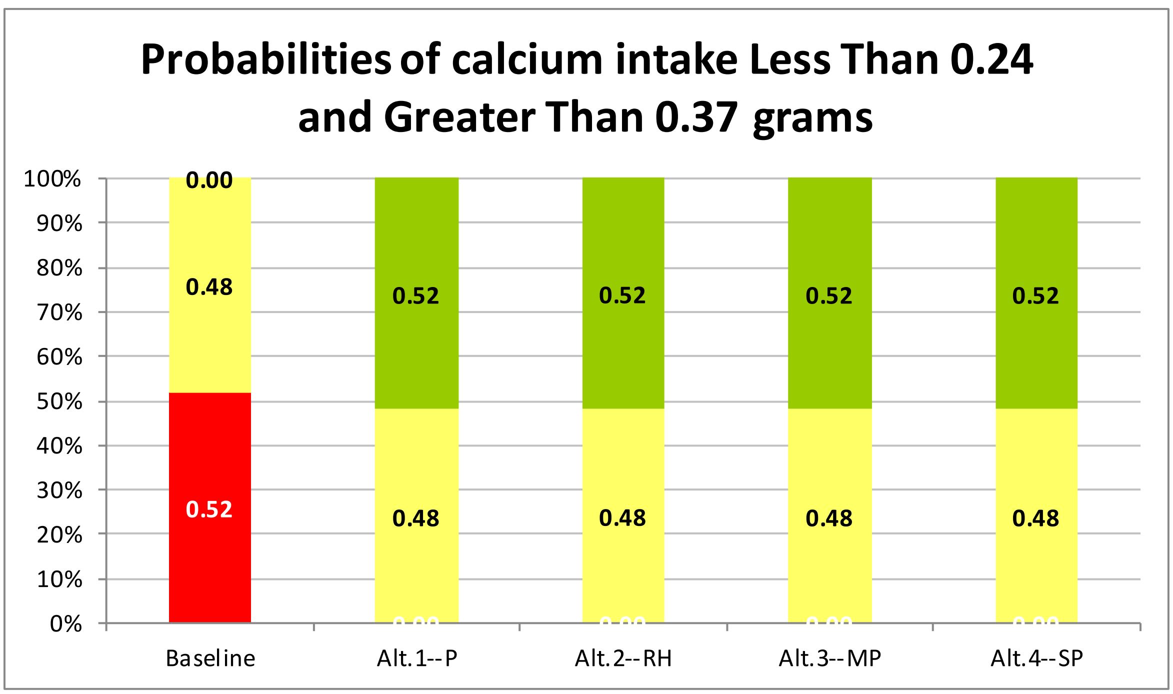

Figure 9b. StopLight Chart for daily calcium consumption per AE on a farm in Abirjiha kebele

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 of 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. 10a). There was also a significant improvement between the baseline and the alternative scenarios in terms of iron intake (averaged 0.17 and 0.24 gram respectively).

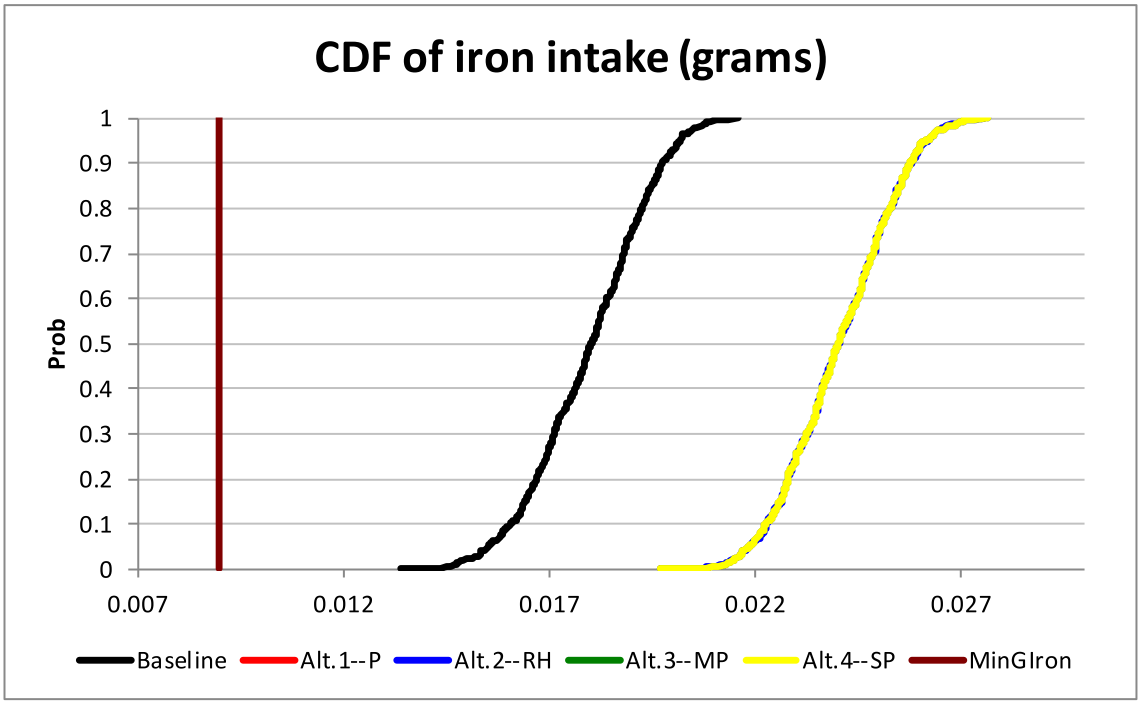

Figure 10a. CDF of daily iron consumption per AE on a farm in Abirjiha kebele

The StopLight chart for iron intake (fig. 10b) indicates that the four alternative scenarios performs 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, 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 in the alternative scenarios. The target values (0.017 and 0.024 grams respectively) are the averages of the baseline and alternative scenarios 500 simulation iterations.

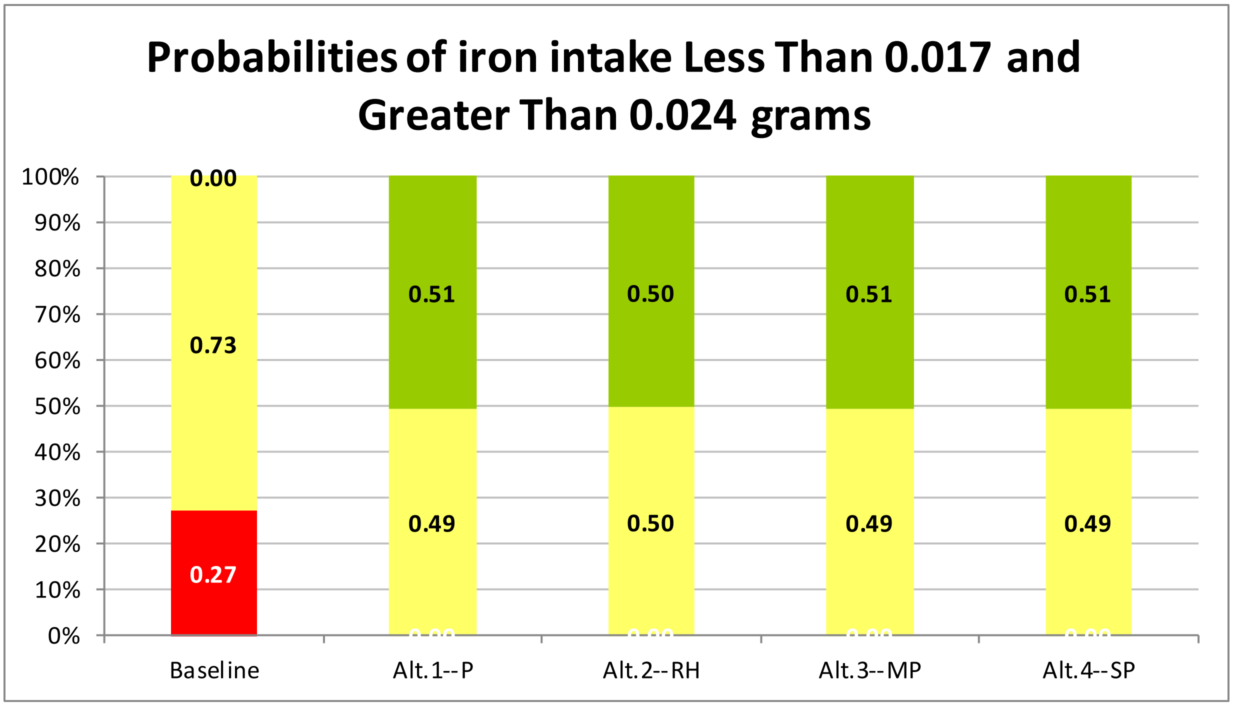

Figure 10b. StopLight Chart for daily iron consumption per AE on a farm inAbirjiha kebele

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 11 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. 11a).

The stop light chart in figure 11b 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 (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.

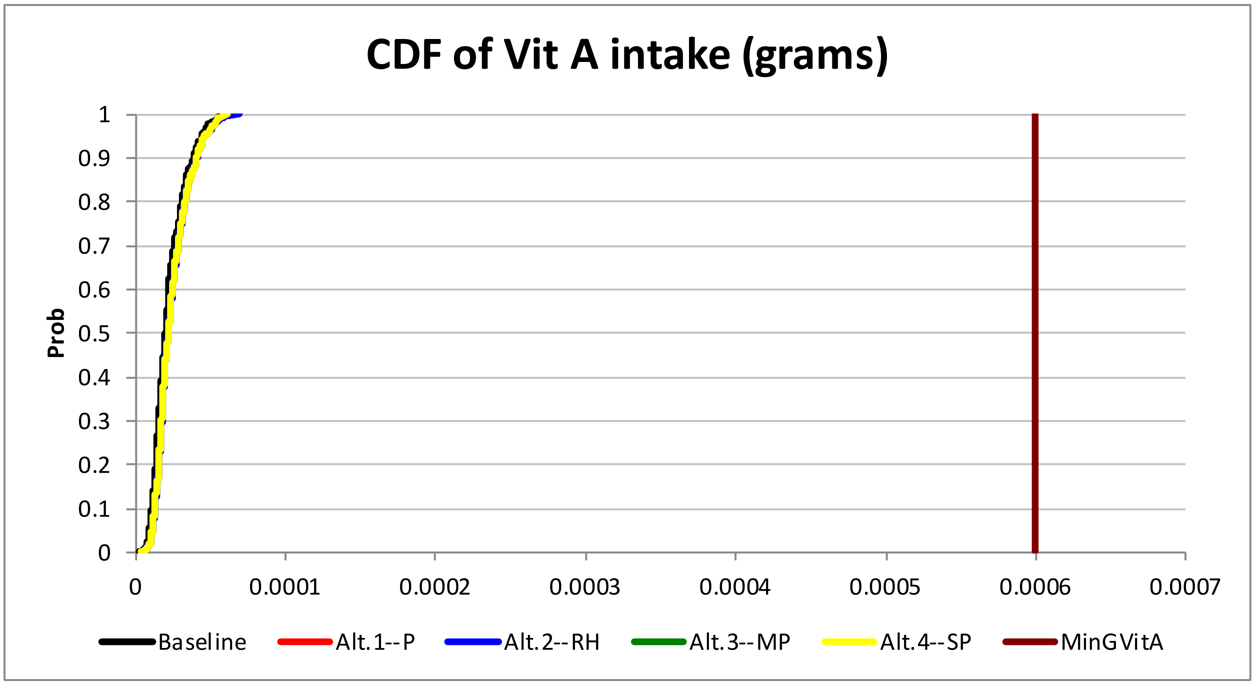

Figure 11a. CDF of daily vitamin A consumption per AE on a farm in Abirjiha kebele

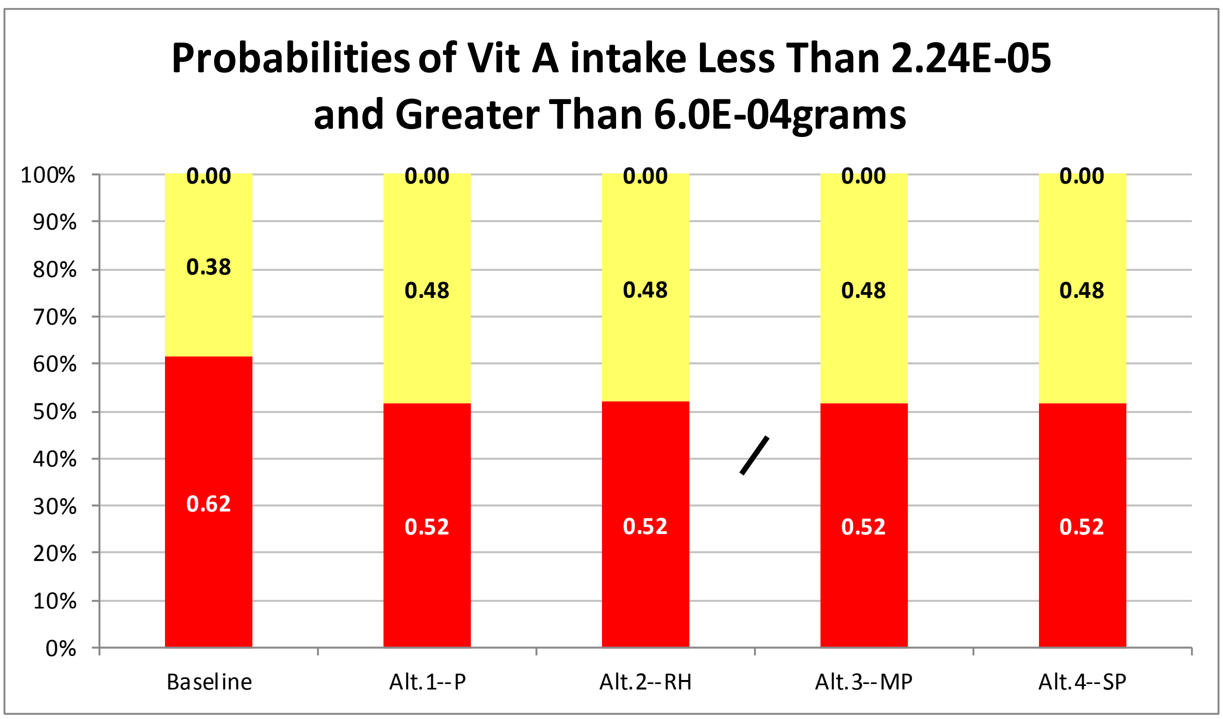

Figure 11b. StopLight Chart for daily vitamin A consumption per AE on a farm in Abirjiha kebele

Ranking of alternative farming technologies

Choosing among risky alternative 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), which allows 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 12a show that the motor pump scenario (Alt. 3) is the most preferred scenario. The next most preferred scenario is the solar pump scenario (Alt. 4) followed by the rope-and-washer scenario (Alt. 2). 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.

The SERF option in Simetar produces as well a risk premium (RP) chart (figure 12b). The chart shows the perceived premium or profit that each risky scenario provides relative to the base scenario at different RAC values represented here by the risk aversion levels. A positive RP over the range of RAC for an alternative scenario means that the alternative scenario is preferred over the baseline while a negative RP would mean the preference of the baseline scenario over the alternative scenario. In this study the alternative scenario three (Alt. 3) that involves the use of gasoline motor pump system has the highest positive RP or profit to decision maker compared to Baseline scenario. Also the difference in RP among the scenarios implies how much additional benefit in terms of wealth a decision maker can get by adopting a higher ranking alternative scenario (e.g. irrigation and fertilizer input) compared to a baseline scenario (non-irrigation).

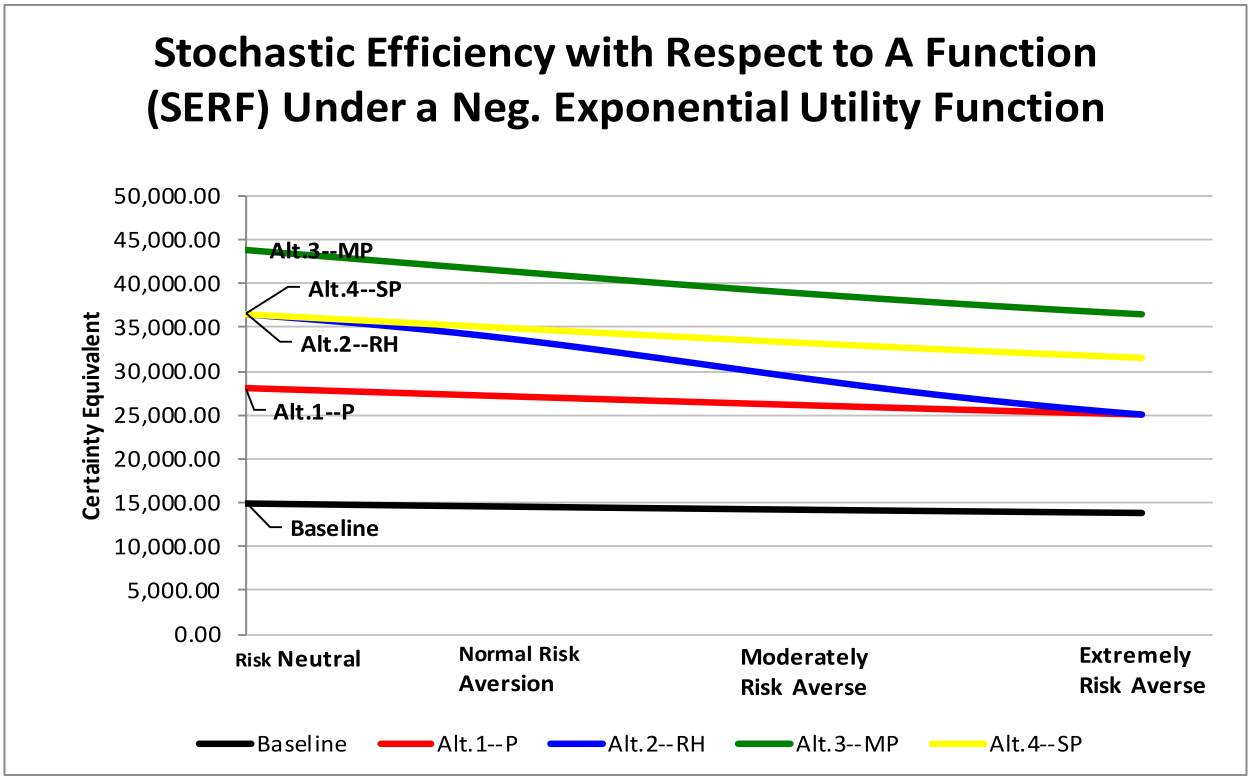

Figure 12a. SERF ranking of alternative farming systems in Abirjiha kebele

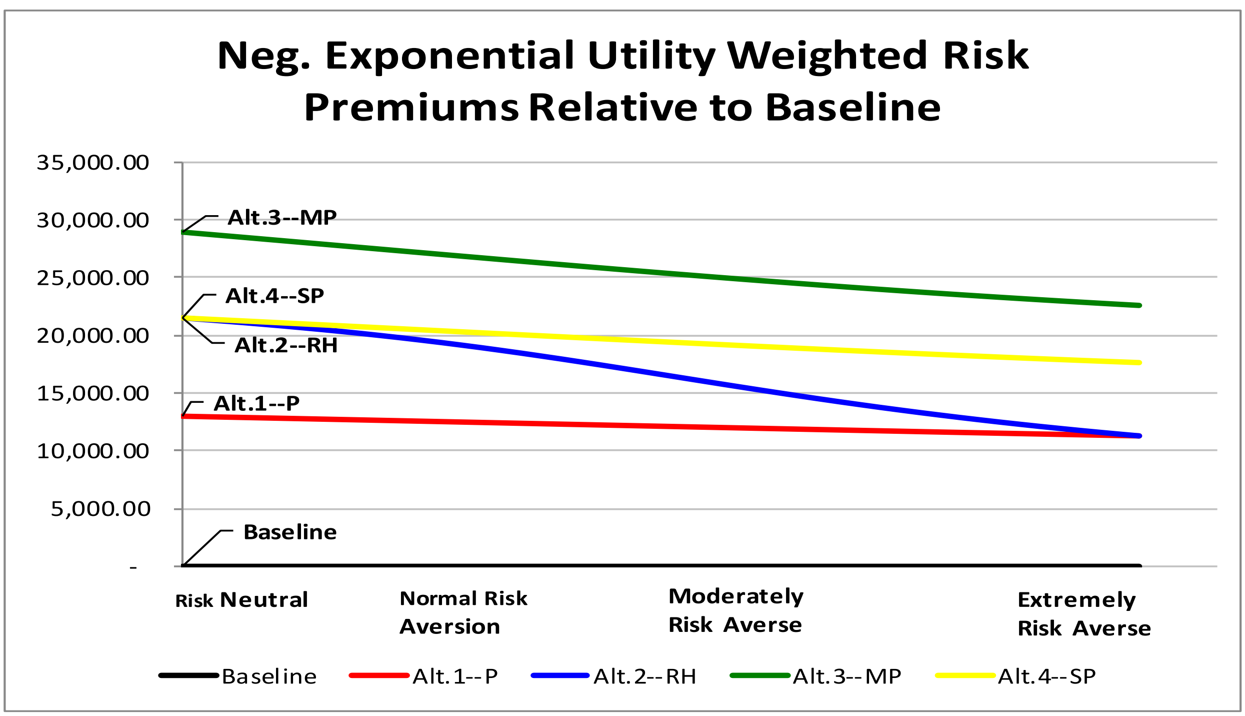

Figure 12b. Risk premiums ranking of alternative farming systems in Abirjiha kebele

Conclusions

The objective of this study was to evaluate the impacts of adopting agricultural technologies (increased fertilizers and irrigation) on household nutrition and farm profitability in Abirjiha kebele, in the Dembia 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 tomato and vetch crops were irrigated during the dry season using one of four alternative water-lifting technologies.

The preferred scenario, consisting of the use of recommended fertilizers in combination with motor-pump irrigation of tomato and fodder crops (Alt. 3), 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 in combination with recommended fertilizers (Alts. 2 and 4, respectively). It is worth noting that the solar pump has the same outcome in terms of profit as the rope and washer pump despite the relatively high investment costs of the solar pump probably due to a slightly higher pumping rate. The baseline scenario was the least preferred of all five scenarios analyzed in this study.

Nutrition levels improved significantly in the four alternative scenarios compared to the baseline scenario. This was a result of the improvements in crop yields due to the application of fertilizer and irrigation technologies. 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.

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.

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Appendix A: Water Lifting Technologies (WLT)

Pulley/bucket system

Rope and washer pump operated by hand

Solar pump system

Motor pump system