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USAID Feed the Future Innovation Laboratory for Small-Scale Irrigation

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Ex Ante **Economic and Nutrition Analysis of Alternative Small Scale Irrigation Systems in Robit kebele-Amhara region of Ethiopia**

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Introduction

Robit kebele is located in Bahir Dar Zuria Woreda, West Gojam Zone in Amhara Region (figure 1), approximately 20 km from Bahir Dar town (Wondatir, Adie, Duncan, 2015). The area has an average elevation of 1848 masl. According to 2007 Ethiopia Census a total of 8900 people are living in the kebele (Republic of Ethiopia, 2008). Mixed farming with livestock is the major farming system in the area where the main crops grown include maize, finger millet, teff, rice, and chick pea alongside livestock production. Food and animal feed crops are grown using both rain in wet season and irrigation water in dry season. Two major cropping seasons are identified in Ethiopia: *Kiremt* and *Bega. Kiremt* is the main rainy season (June-September) during which the main field crops are grown and harvested in *Meher* season. Irrigated crops such as tomatoes, grass peas, chick peas, cabbage and onions are grown during the *Bega* season (dry from October to January). The main sources of irrigation water are shallow wells, lake and river diversion. The potential of irrigation from groundwater and experience in smallholder irrigation is relatively high in Robit kebele where in 2014, about 1820 ha of land was irrigated and around 4000 individual wells were recorded in the kebele (Assefa, 2015).

Most of the households keep cattle, small ruminants, poultry and bees (apiculture). Cattle are basically raised to meet draught power requirements while milk, meat, manure, dung cake, breeding replacement stock are income sources, but are of secondary importance. The majority of the milk produced is retained for home consumption. However, some milk is processed into butter for sale and family consumption. Donkeys are as well kept, mainly for transportation purposes.

The level of agricultural and livestock input (seed, fertilizers, animal breed improvement) in Robit is better relative to a typical rural poor farm in a developing country. Besides the low level of animal improvement (crossbred animals are fewer), the use of agricultural inputs such as fertilizers, irrigation and improved seeds are relatively fair/good sometimes higher in comparison to the rates recommended by the government (e.g. fertilizers).

A farm level analysis model (FARMSIM) is used to simulate and identify the impact of new agricultural farming technologies on farm profit and nutrition for a typical farming household. 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 and an alternative farming system simultaneously. Risk for crop yields, livestock production (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. Stochastic annual crop yields are simulated from a multivariate empirical probability distributions estimated using 32 years of crop yields generated by the APEX model (Agricultural Policy / Environmental eXtender) using the most recent 32 years of local weather data, soil conditions, and an internationally validated crop growth modeling algorithm.
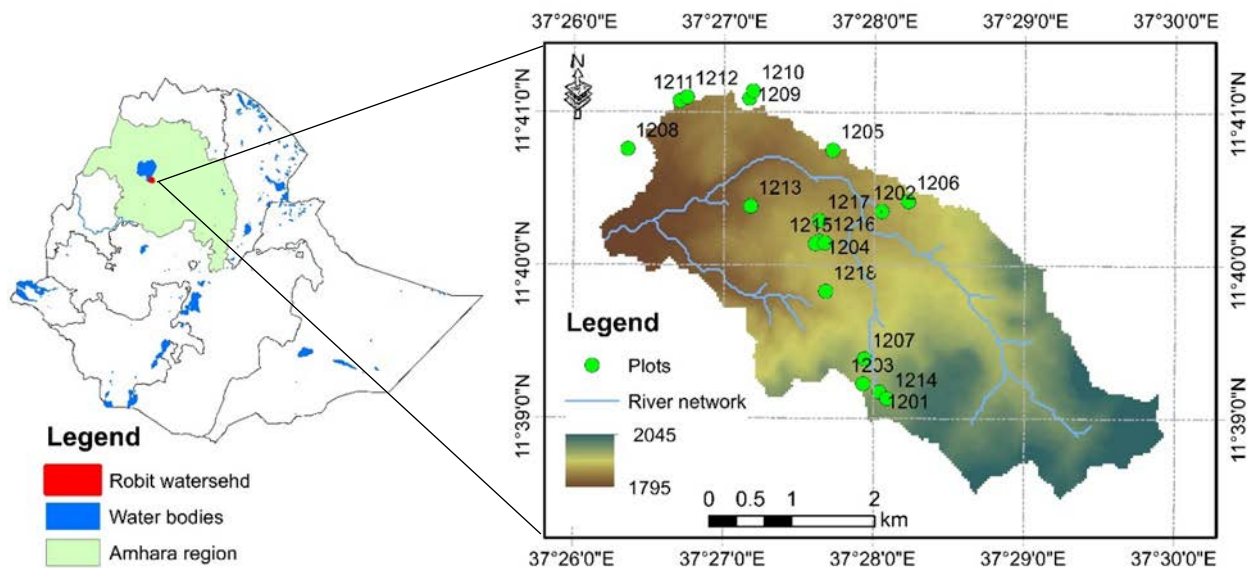
Figure 1. Location of Robit Bata watershed in Robit kebele, Amhara region

Data

The farm level information on crop and livestock that was input in FARMSIM came from both the ILRI-LIVES[1] and ILSSI household surveys data collected respectively in January of 2014 and 2015. The household sample size for Robit kebele comprised about 60 households. The survey shows that the major crops grown, by area, in Robit kebele are maize (728 Ha), millet (708 Ha), and teff (266 Ha) on an estimated total cropland of 2390 Ha (rain-fed and irrigated). Irrigated onion was chosen over tomato as the vegetable crop to study given its limited perishability. The pastureland occupies about 523 Ha.

The number of farmers who irrigated the crops was about 41% according to the ILRI-LIVES survey Among the total number of respondents, 33% indicated they have a motor pump while only 25% indicated they have a plot under irrigation. Fertilizer use rates (Urea and DAP) are about equal to or higher than the recommended rates (see tables below). For instance, survey results show that the rates applied for maize and millet are equal to or higher than the actual current or recommended fertilizer quantities. The socio-economic status of farmers appears to be better in Robit compared to an average small scale farmer; this may be due to additional income revenue from the sale of a cash crop such as chat, a commonly grown and traded crop in Robit (Gebey and Mekuriaw, 2013). Chemical use (herbicide and pesticide) is very low or non-existent in most of the surveyed farms in Robit Kebele. Also, the level of farm labor hiring for agricultural production is low since family members are expected to perform most of the agricultural tasks required for farming. It's worth noting that, the use of actual crops to feed animals is not common and most of the animal feed come from crop residues.

Farmers fertilizer rates (survey) vs. current and recommended rates

Maize

	ILRI-LIVES-Survey (baseline/current)	Literature	
		Current	Recommended
Urea (Kgs/Ha)	110.6	98	100
DAP (Kgs/Ha)	99.8	98	100

Teff

	ILRI-LIVES-Survey (baseline/current)	Literature	
		Current	Recommended
Urea (Kgs/Ha)	36	53	100
DAP (Kgs/Ha)	88	53	100

Millet

	ILRI-LIVES-Survey (baseline/current)	Literature	
		Current	Recommended
Urea (Kgs/Ha)	83	0	0
DAP (Kgs/Ha)	146	70	100

Note: Numbers from literature are drawn from Dile & Srinivasan (2014)

No survey data for current fertilizer application rates on onions was available from the Robit survey. Other Kebeles within the Bahir Dar Zuria Woreda show an application of about 100Kg/ha of Urea and no application of DAP.

Scenarios description

Baseline scenario: current fertilizer + current tillage + no irrigation

For the baseline scenario, the major crops grown in the wet season are: maize, teff and millet in the food crops category while onion is considered in the vegetable category. With minimal agricultural input (fertilizer, irrigation, improved seeds), the crop yields are expected to be low. However, since these crops are grown during the main rainy season, the water stress is not a constraint. The main limitation for a typical rural farm in Ethiopia would come from the lack of sufficient use of fertilizers and improved seeds. This is not the case for the Robit household

farms where the levels of fertilizer use (Urea and DAP) for the baseline are close to the recommended rates and higher than the average current fertilizers rates in the literature.

Alternative scenarios

Due to the issue of hardpan soil in Robit, we deemed it necessary to consider it as an important yield factor for all of the alternative scenarios analyzed. In general, only a deep tillage can break down the hard layers of soil and allow the crops to benefit from fertilizer and irrigation. Moreover, given that the level of fertilizers applied by farmers in Robit is close to the recommended rates, no additional quantity and costs of fertilizer are assumed for the alternative scenarios. Mainly the type of tillage (current and deep) and irrigation will determine the change in yields. Increases in yields are expected for grain crops with deep tillage while yield increases for onions is expected with irrigation in the dry season. Five different water lifting technologies are tested in this study: pulley/bucket; rope and washer pump operated by hand, animal, motor and solar (see pictures in Appendix A). These tools are evaluated as to their capacity to provide necessary water to a maximum irrigable onion cropland of 787 ha without water stress. Before analyzing the economic and nutritional impacts of farming technologies, a Soil and Water Assessment Tool (SWAT) model was used to assess soil and water characteristics at the watershed level. SWAT helped assess the availability of irrigation water in the watershed as well the total potential irrigable land.

The combination of two alternative scenarios (fertilizer level and tillage type) and five water lifting technologies produced ten alternative scenarios to compare with the current conditions or baseline scenario.

-Alt. scenario 1, 3, 5, 7 & 9: irrigated onions + recommended fertilizers + current tillage

 The same major crops (teff, millet and maize) are grown during the rainy season but in addition irrigated onions are grown during the dry season. Five alternative irrigations systems are tested for this scenario.

-**Alt. scenario 2, 4, 6, 8 & 10: irrigated onions + recommended fertilizers + deep tillage**

 The same major crops (teff, millet and maize) are grown during the rainy season in addition to irrigated onions during the dry season. Five alternative irrigations systems are tested for this scenario.

Assessment of water lifting technologies

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

1) Number of active family members (adults) who will carry out the irrigation: 2
2) Number of irrigation hours per family member per irrigation day: 4
3) Number of days per season the farmers are irrigating if we assume 2 days per week of irrigation during a period of three and half months (January-mid April): 28
4) Total number of hours of irrigation per season: 2*4*28 = 224 hours
5) Pumping rates (liter/min) for the different water lifting technologies:
   - Pulley/bucket: 8 liters/min
   - Rope operated by hand[2]: 20 liters/min
   - Rope operated by animal power[3]: 60 liters/min
   - Rope operated by motor power from gasoline[4]: 170 liters/min
   - Rope operated by motor power from solar[5]: 24 liters/min

SWAT model simulation results determined that enough ground water was available to pump for irrigation (Bizimana et al., 2014). Crop yields are simulated by APEX for different levels of water stress. The irrigator's equation (see Martin, 2011) is 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 (liters/min)

   T: time (min) for irrigation

   d: depth of irrigation water applied (mm)

   A: area covered (m2 or ha)

Knowing the total amount of water (mm) required to irrigate a crop for the entire dry season and the total amount of water delivered by each water lifting technology per hectare (based on pumping rate and irrigation hours), we compute the fraction of water supply provided by each technology. Given the total irrigable land available for a crop (e.g. onion) and its water

requirements, we use the fraction of water supply by each technology to compute the fraction of available cropland that can be irrigated with minimal water stress for each water lifting technology.

For instance, due to its high pumping rate, the rope and washer pump operated by a gasoline motor would in most cases supply more than enough water to irrigate all available cropland. On the other hand, a rope and washer pump operated by hand, solar motor or the pulley system, assuming the same number of irrigation hours, does not provide sufficient water to irrigate all of the available cropland. Taking into account the initial investment and operating costs for motor and solar systems in the economic analysis, the use of a rope and washer pump operated by

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[2] Nederstigt and Van del Wal (2011)/PRATICA Foundation

[3] http://www.ropepumps.org/horse.html/ PRACTICA Foundation

[4] IWMI field studies conducted in 2015 on behalf of ILSSI project

[5] Mzuzu University in Malawi: http://old.solar-aid.org/project_water_pump/

animal power could be the preferred options for an average farmer to be able to supply enough water to crops during the dry season and make the investment in irrigation worthwhile.

Simulation results and scenario analysis

The results presented below in the stoplight chart and CDF graphs (except for NPV) represent the year 3 simulation results from a 5-year simulation period. The 11 scenarios (baseline and 10 alternatives) are defined below:

- ✓ Baseline: current fertilizer + current tillage + no irrigation

- ✓ Alt.1 (Pulley-RF-CT): irrigate onions with pulley + recommended fertilizers + current tillage
- ✓ Alt.2 (Pulley-RF-DT): irrigate onions with pulley + recommended fertilizers + deep tillage
- ✓ Alt.3 (Rope-Hand-RF-CT): irrigate onions with rope pump operated by hand + recommended fertilizers + current tillage
- ✓ Alt.4 (Rope-Hand-RF-DT): irrigate onions with rope pump operated by hand + recommended fertilizers + deep tillage
- ✓ Alt.5 (Rope-Animal-RF-CT): irrigate onions with rope pump operated by animal (ox, horse) + recommended fertilizers + current tillage
- ✓ Alt.6 (Rope-Animal-RF-DT): irrigate onions with rope pump operated by animal (ox, horse) + recommended fertilizers + deep tillage
- ✓ Alt.7 (Rope-Motor-RF-CT): irrigate onions with rope pump operated by gasoline motor + recommended fertilizers + current tillage
- ✓ Alt.8 (Rope-Motor-RF-DT): irrigate onions with rope pump operated by gasoline motor + recommended fertilizers + deep tillage
- ✓ Alt.9 (Rope-Solar-RF-CT): irrigate onions with rope pump operated by solar motor + recommended fertilizers + current tillage
- ✓ Alt.10 (Rope-Solar-RF-DT): irrigate onions with rope pump operated by solar motor + recommended fertilizers + deep tillage

Note that deep tillage is applied only to cereal crops (teff, maize and millet) to break the hard pan soil while the vegetables (onions) are grown on selected good soils. Based on water needed for irrigated onions in the dry season, only the rope pump operated by gasoline motor is able to provide the required water quantity to onions (0% water stress level) for the maximum irrigable onion land of 787 ha. The pulley irrigation system covers only 8% of the maximum land while the rope pump operated by hand irrigation system covers only 20% of the maximum irrigable land. The rope pump operated by animal power and solar motor cover respectively 60% and 24% of the maximum irrigable land.

The farm level simulation results for the 11 scenarios showed differences not only between the baseline and the alternative scenarios but also among the alternative scenarios in terms of financial variables (net cash farm income and ending cash reserves) and nutrition.

Other simulation assumptions

First, to show the full potential of adopting new technologies, we assumed that the alternative farming technologies (alternative scenarios) simulated for this study were adopted at 100%. 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 five-year economic forecast, market selling price in each of the five years was assumed to equal the average selling price of year 1 for each crop sold.

NPV (Net Present Value)

The NPV is an indicator that assesses the feasibility/profitability of an investment or project over a certain period of time. In this study, a representative farm in Robit Kebele is simulated for 5 years to evaluate the adoption of new agricultural technologies (fertilizer, tillage, and irrigation). Five water lifting technologies (pulley/bucket, rope pump operated by hand, animal, gasoline motor and solar motor) and two agricultural practices (tillage and fertilizer) are evaluated to determine the most efficient and affordable technology for the farmer.

Overall, the NPV results indicate clearly that it is worth investing in irrigation, fertilizer application and deep tillage as shown by the cumulative distribution function or CDF (figure 2a). The use of recommended fertilizers and deep tillage on grain crops in combination with onion irrigation using either rope pump operated by animal power or a gasoline motor showed outstanding performance (Alt. 5, 6, 7 and 8), in that their CDF values lie to the right of the other scenarios for all 500 draws of the simulation model. The second best alternative scenarios are Alt. 4 and 10 that involve the use of rope pump operated by hand and solar motor. The use of pulley/bucket with current tillage and fertilizer application showed the lowest NPV values along with the baseline scenario.
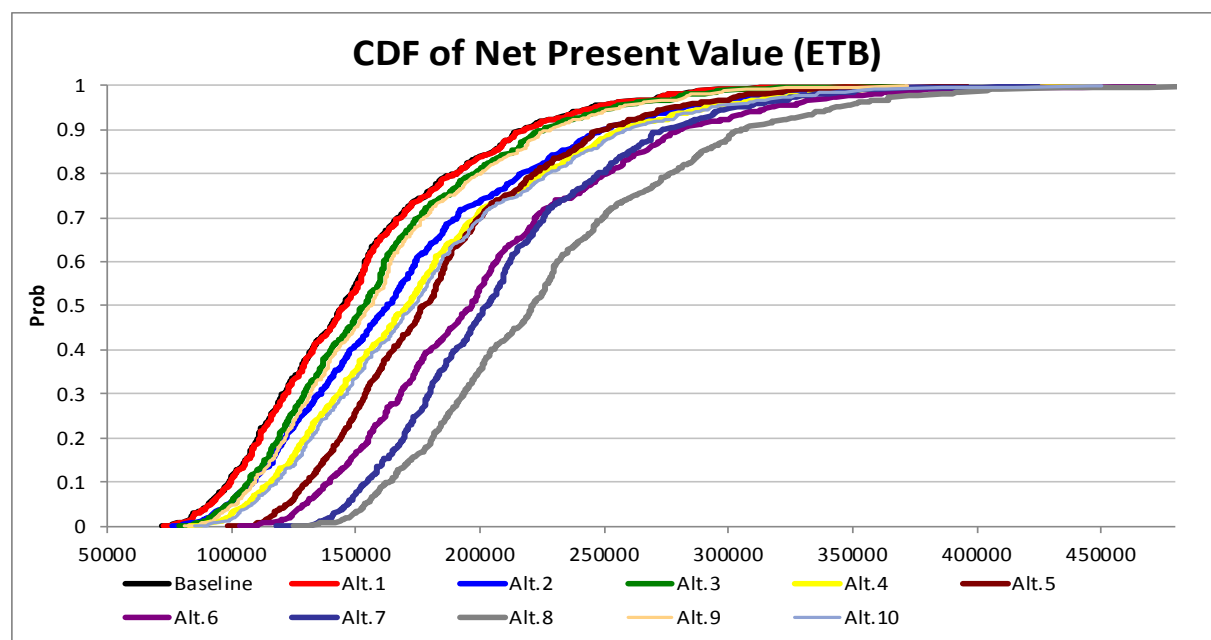

Figure 2a. Net present value for the 11 scenarios

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Baseline: No irrigation + current tillage and fertilizer applications
Alt. 1:   Use of pulley/RF/CT
Alt. 2:   Use of pulley/RF/DT
Alt. 3:   Use of rope & washer pump operated by hand/RF/CT
Alt. 4:   Use of rope & washer pump operated by hand/RF/DT
Alt. 5:   Use of rope & washer pump operated by animal /RF/CT
Alt. 6:   Use of rope & washer pump operated by animal /RF/DT
Alt. 7:   Use of rope & washer pump operated by gasoline motor /RF/CT
Alt. 8:   Use of rope & washer pump operated by gasoline motor /RF/DT
Alt. 9:   Use of rope & washer pump operated by solar motor /RF/CT
Alt. 10:   Use of rope & washer pump operated by solar motor/RF/DT

Note: RF=recommended fertilizer/CT=current tillage/DT=deep tillage

The stoplight chart presents the probabilities of NPV that are less than 160,000 ETB (Ethiopian Birr) (red), greater than 220,000 ETB (green) and between the two target values (yellow) for the five year planning horizon. The target values are the averages of NPV for the baseline and pulley system alternative scenario (lower bound) and the two best performing alternative scenarios (Alt. 6 & 8) (upper bound). There is a 65% chance that NPV will be less than 160,000 ETB for a farmer who does not adopt the technology package (baseline scenario) and only a 9% chance that NPV will exceed 220,000 ETB (figure 2b). As for farmers who apply recommended fertilizer and deep tillage for the grain crops and grow irrigated onions in the dry season using a rope pump operated by animal or gasoline motor the probability that NPV will exceed 220,000 ETB is respectively 32 and 51 percent. The only barrier for the best performing scenarios (motor) is the initial investment in water lifting technology which is two times higher for farmers using a rope pump operated by solar and gasoline motor than those using animal power. However, the NPV results strongly suggest that the investment in gasoline motor and animal power will pay large dividends by increasing income and wealth.
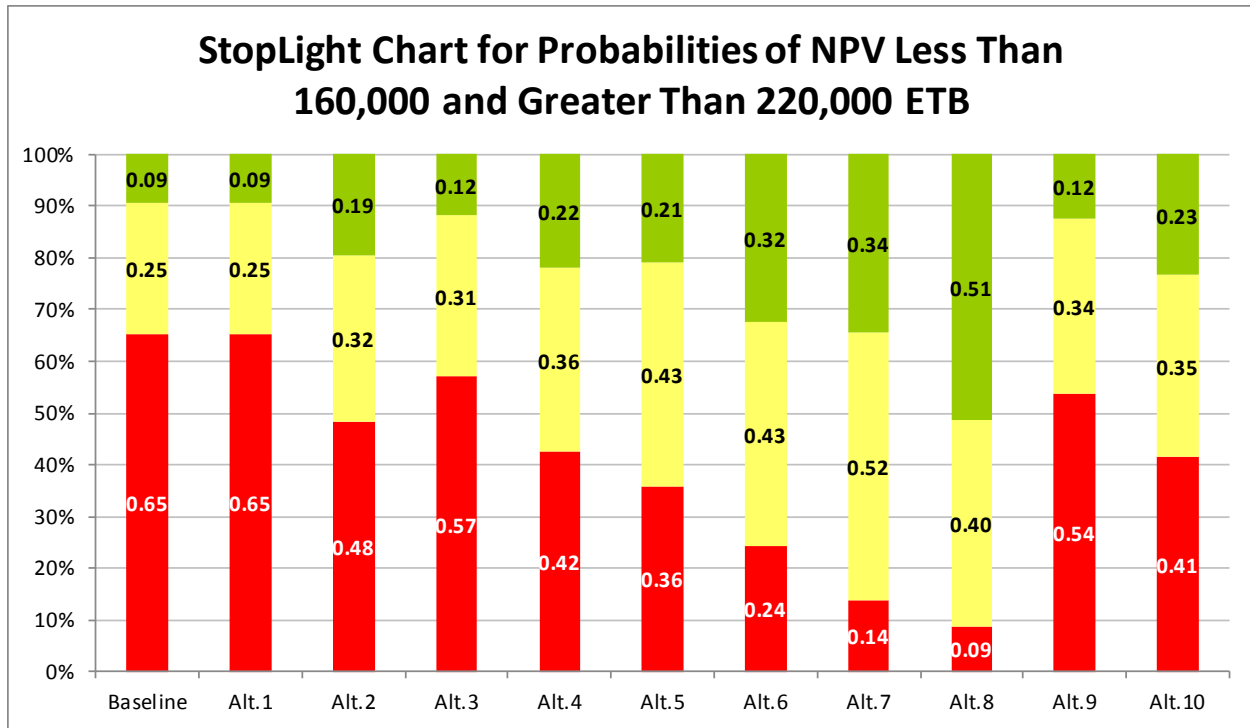
StopLight Chart for Probabilities of NPV Less Than 160,000 and Greater Than 220,000 ETB

Figure 2b. Stoplight chart for the NPV

NCFI (Net Cash Farm Income)

The annual net cash farm income (NFCI) simulation results represent in figure 3a the profit of a farm for the baseline and the 10 alternative scenarios in year 3. Even though the CDF graph shows scenarios that are close to each other, alternative scenarios 5, 6, 7 & 8 generated higher NCFI than the rest of scenarios (baseline and Alt. 1- 4) at least at the 60 % (and below) probability mark. Alternative scenarios 6 & 8 which involve the use of recommended fertilizer rates, deep tillage and irrigation by a rope pump operated by animal power and gasoline motor generated higher levels of NCFI at all probability levels which makes them the preferred scenarios for decision makers.
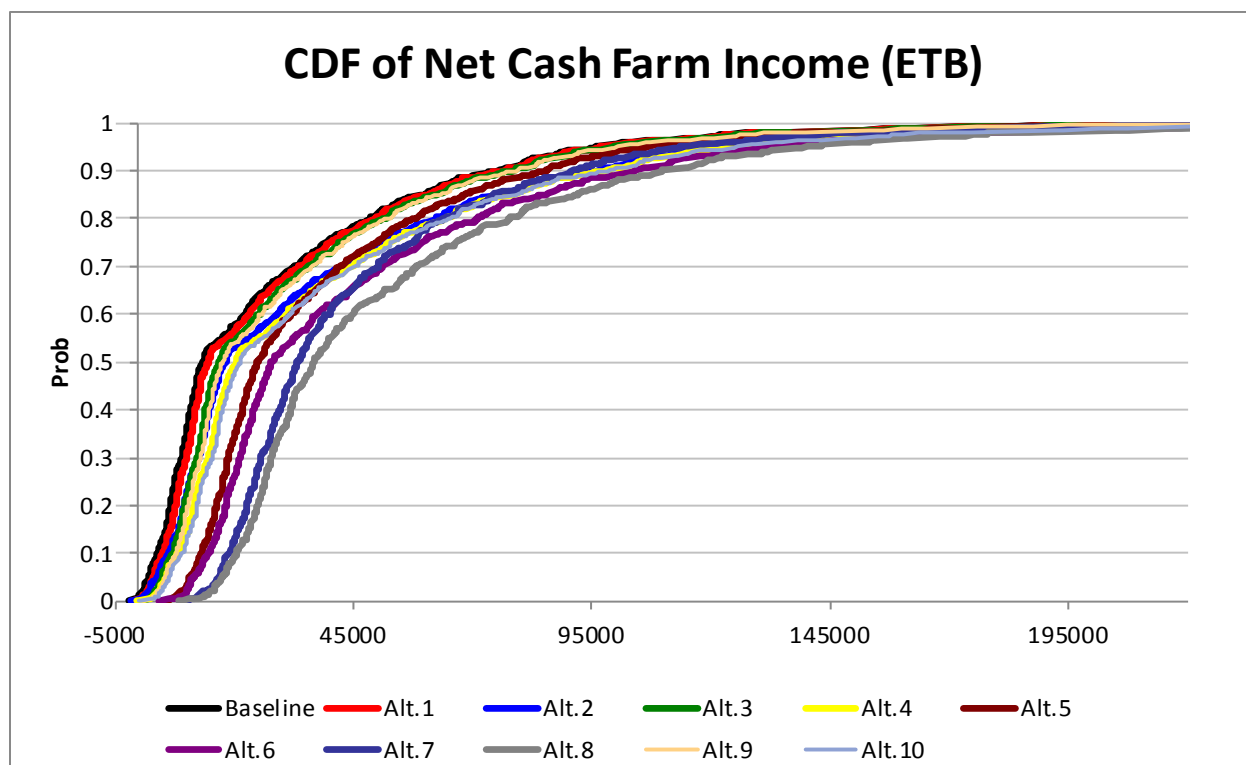
Figure 3a. Net cash farm income for the 11 scenarios

The stoplight chart for NCFI in year 3 of the planning horizon shows a 68% probability of having NCFI less than 30,000 ETB and a 19% chance that NCFI exceeds 50,000 ETB (Figure 3b) for a representative farmer who does not adopt the technology package (Baseline scenario). There are however a 31% and 37% chance that annual NCFI will exceed 50000 ETB for a farmer who uses a rope pump operated by animal power or gasoline motor (Alt. 6 & 8) to irrigate onions and applies recommended fertilizer and deep tillage to grow grain crops. The farmer who adopts the technology package (Alt. 6 & 8) has respectively about 52% and 36% probability of having a NCFI less than 30,000 ETB in year three. Alternative scenarios 4 & 10, which use a rope and washer pump operated by hand and solar motor to irrigate onion along a deep tillage and fertilizer applications to grow grain crops, are the second most preferred scenarios for decision makers in terms of profit generation. The baseline and pulley systems have the lowest NCFI values.
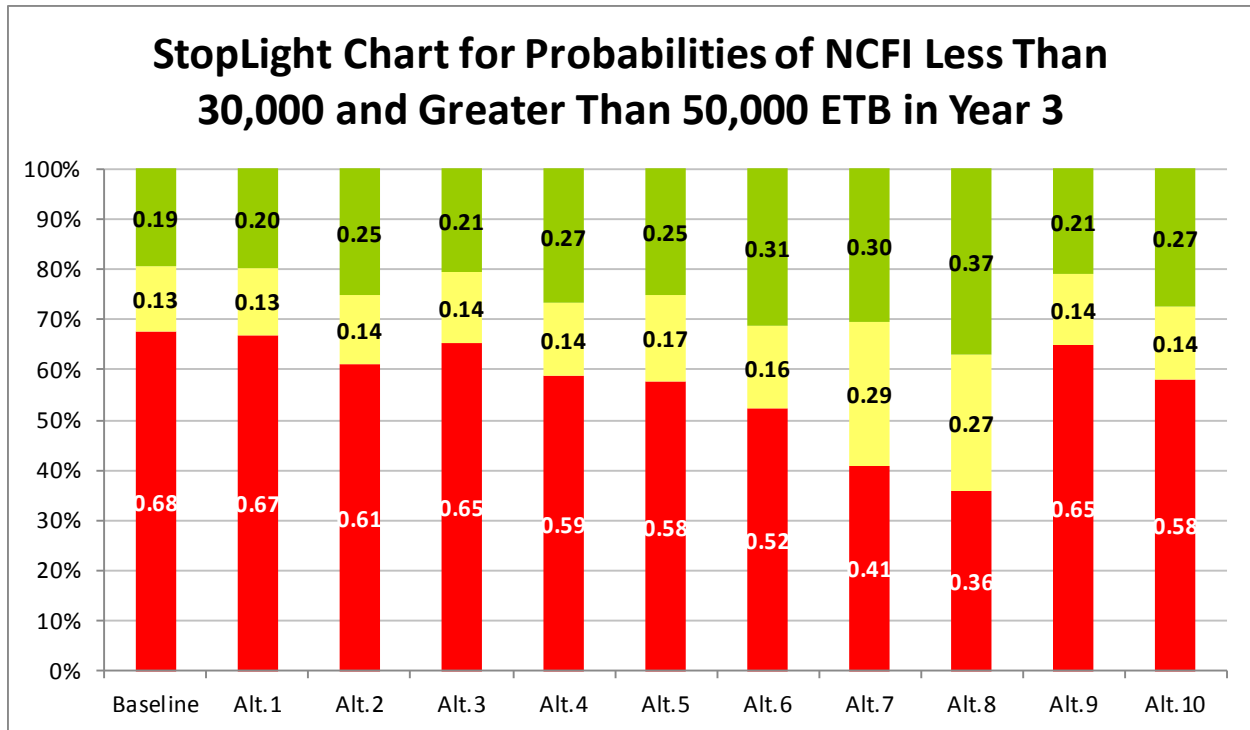
StopLight Chart for Probabilities of NCFI Less Than 30,000 and Greater Than 50,000 ETB in Year 3

Figure 3b. Stoplight chart for the NCFI

EC (Ending Cash Reserves)

The annual ending cash reserve simulation results in figure 4a highlight once again the performance of the alternative scenarios 5, 6, 7 & 8 that involve the use of a rope pump operated by animal and gasoline motor to irrigate onions. Even though alternative scenarios 6, 7, 4, 10 and 5 lines cross at or below the 70% probability mark, the results highlight the performance of alternative scenarios 4, 6, 8 & 10 that apply a deep tillage (higher ending cash reserves) compared to alternative scenarios 5, 7 & 9 that use current tillage. The baseline scenario with current tillage and no irrigation along with alternative scenario 1 (Alt. 1) which uses pulley/bucket to irrigate onions with current tillage practice are the worst performing scenarios (lower ending cash reserves).
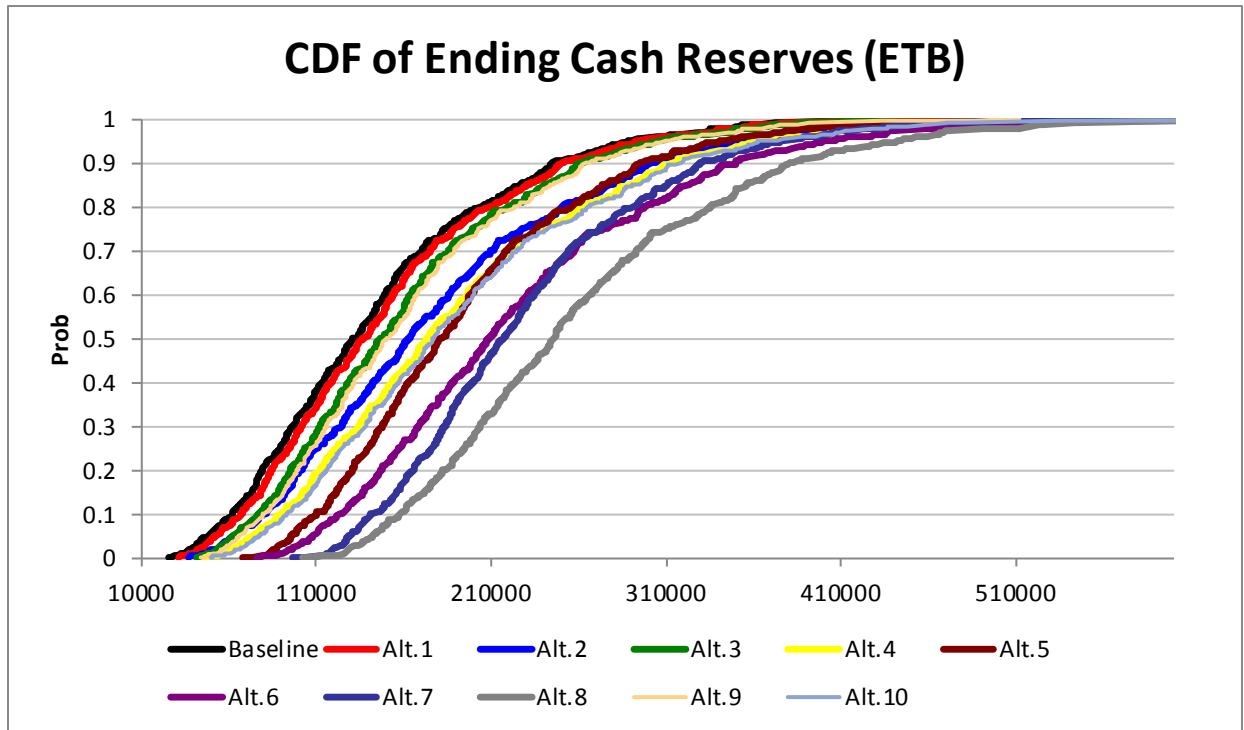
CDF of Ending Cash Reserves (ETB)

Figure 4a. Ending cash reserve for 11 scenarios

The stoplight chart for ending cash shows a 60% probability of having an ending cash reserve in year 5 of less than 150,000 ETB for a representative farmer who does not adopt the technology package (Baseline scenario) compared to 8% for a farmer who adopts a rope pump operated by a gasoline motor irrigation technology, applies recommended fertilizers and deep tillage (Alt. 8) (Figure 4b.). Alternatively, there is a 53% probability of having ending cash reserves of more than 240,000 ETB for a farmer who adopts the technology package (Alt. 8) compared to the Baseline scenario with only a 12% probability that the ending cash reserve would exceed 240,000 ETB. Using a pulley/bucket to irrigate onions and applying recommended fertilizer rates and a deep tillage practice to grow grain crops (Alt.2) performs slightly better than the Baseline scenario but is outperformed by the rope pump operated by hand (Alt.4) and rope operated by animal/motor/solar power (Alt. 5, 6, 7 & 10) alternative scenarios. Notice that all the scenarios with deep tillage performed better than their counterparts with current tillage practices.
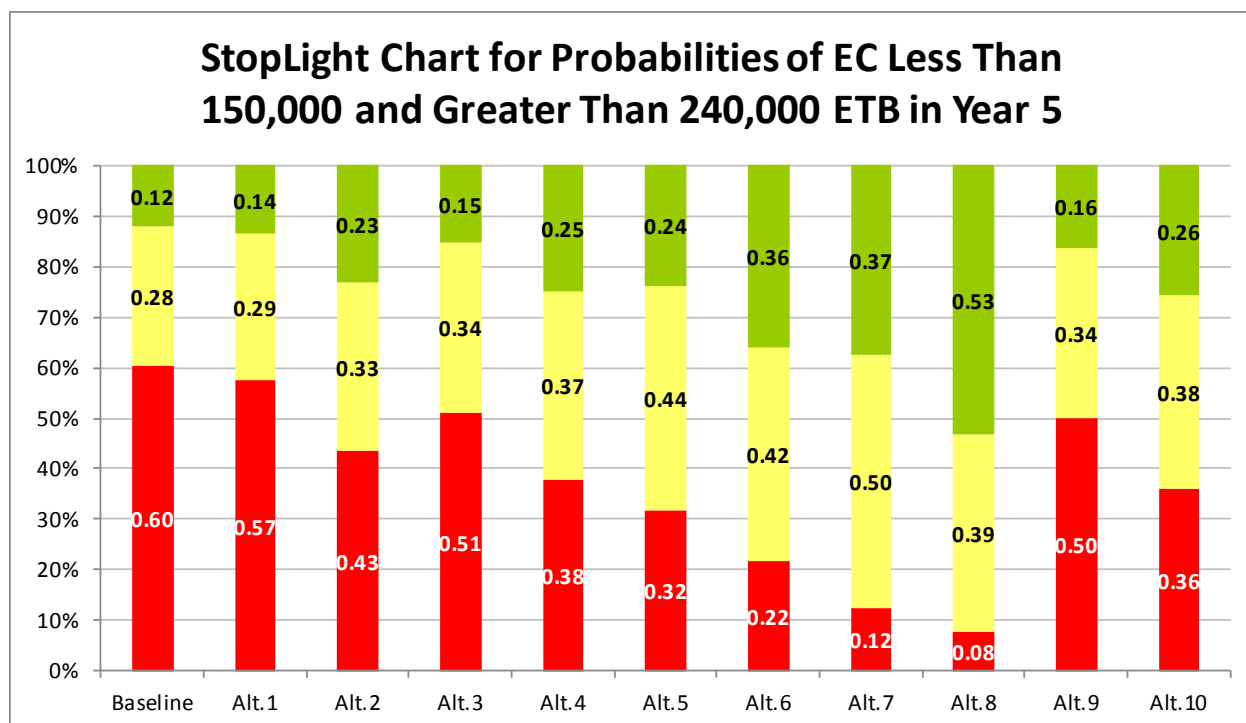
Figure 4b. Stoplight chart for the ending cash reserves (EC)

Since grain crops in Robit are mainly used for family consumption, the increases in farm revenue in each of the alternative scenarios were due almost entirely to the sale of surplus onion. In alternative scenarios 6 & 8 the forecasted sales of onions contributed, on average, 87% of the total crops receipts and 100% of the net cash (profit) for the five-year planning horizon.

Scenario ranking

Decision makers rank risky alternatives based on their utility for income (or wealth) and risk. Many ranking procedures (e.g., mean, standard deviation, coefficient of variation, etc.) do not take into account utility 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 the Robit kebele study we use SERF to identify the preferred risky alternatives given its many advantages over the other ranking approaches.

SERF assumes a utility function with a risk aversion range of U(r1(z), r2(z)) and evaluates the CEs over a range of risk aversion coefficients (RAC) between an LRAC (lower RAC) and an URAC (upper RAC). The range can vary from LRAC = 0 (risk neutral) to URAC = 1 (risk averse), allowing 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 eleven scenarios (a baseline and ten alternative scenarios) were ranked based on the year 3 simulation results of NCFI. Results in figure 5a show that alternative scenario 8 which involves the use of recommended fertilizer rates, deep tillage and irrigation by a pump operated by a gasoline motor (Alt. 8) is the most preferred scenario ranking higher than any other scenario on the entire range of RAC represented here by different levels of risk aversion (risk neutral to extremely risk averse). The next most preferred scenarios are, by order of importance, the alternative scenarios seven, six and five (Alts. 7, 6, and 5). These scenarios involve respectively the use of a rope and washer pump operated by gasoline motor under current tillage, a rope and washer pump operated by animal power with deep tillage and a rope and washer operated by animal power with current tillage (Alts. 7, 6 and 5). Besides Alt.8, the alternative scenarios seven, six and five (Alts. 7, 6 & 5) are distinctively ranking higher than the rest of other scenarios with a clear edge of Alt. 7 over Alts.5 and 6. The Baseline scenario is the lowest ranking among all scenarios followed by the pulley and bucket irrigation scenario (Alt. 1). Notice that as the risk aversion level increases, the CE amount decreases as well emphasizing the behavior of a risk aversion decision maker who is willing to get less money or wealth in return of reduced risk.
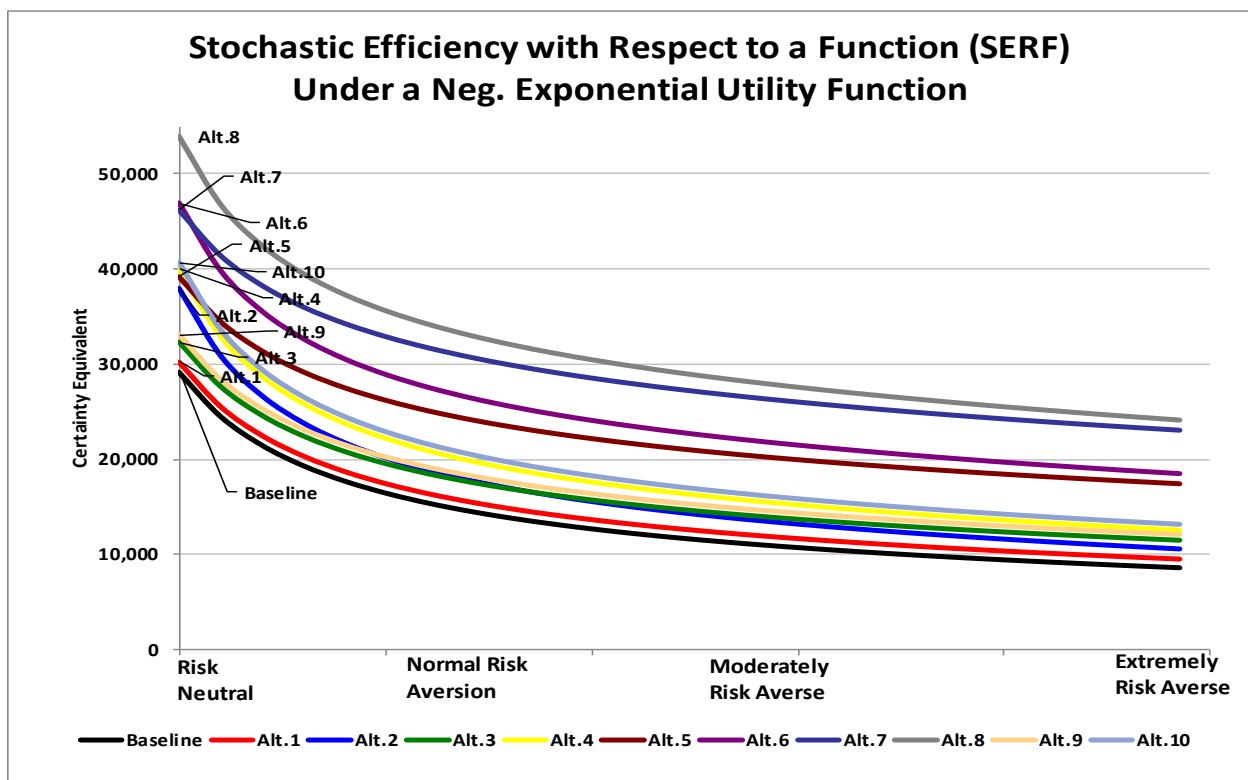

Figure 5a. SERF ranking of alternative farming systems in Robit kebele

The SERF option in Simetar produces as well a risk premium (RP) chart (Figure 5b). The chart shows the perceived premium 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. Also the difference in RP implies how much additional benefit in terms of wealth a decision maker can get by adopting a higher ranking alternative scenario (irrigation and fertilizer input) compared to a baseline scenario (non-irrigation).
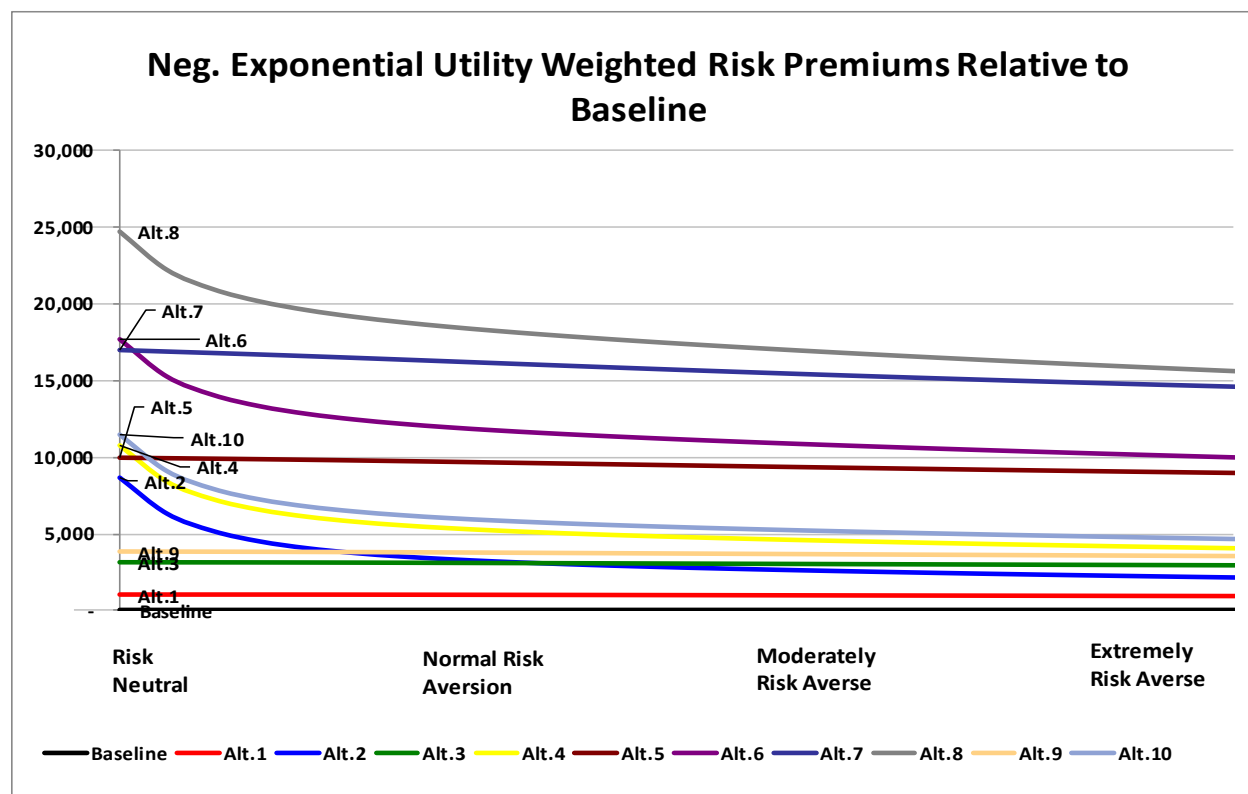

Figure 5b. Risk premiums ranking of alternative farming systems in Robit kebele

<u>Nutrition</u>

In general adoption of agricultural technologies when properly used led to an increase in quantity and variety of crops produced. The implications on the nutrition however vary according to the type of crops grown and consumed. Moreover, the surplus food can be sold at the market and the resulting revenue can be used to buy food items needed to complement the nutrition requirements. In this case, the simulation results show an increase in quantities available to the farm family under all of the alternative scenarios for all nutrition variables (calories, proteins, fat, calcium, iron and vitamin A) except the vitamin A. Also the minimum requirements per adult equivalent per day are met for calories, proteins and iron only but there are nutritional deficiencies for fat, calcium and vitamin A. Clearly food supplements (either through purchase or farming) to meet the minimum requirements for fat, calcium and vitamin A will be needed to meet the nutritional requirements and the well-being of the families in Robit Kebele.

Conclusions

The objective of the study is to evaluate the impact of adopting agricultural technology (fertilizers, irrigation, and tillage) on household nutrition and farm profitability in Robit Kebele, Amhara region of Ethiopia. The baseline scenario with no irrigation and use of current fertilizer and tillage is compared to 10 alternative scenarios where fertilizers and deep tillage farming practices are applied to grow grain crops during the wet season alongside growing irrigated onions during the dry season.

The use of recommended fertilizers with current or deep tillage on grain crops in combination with onion irrigation using a rope pump operated by a gasoline motor were the best alternative farming system (Alt. 7 & 8). The second best performing alternative scenarios were Alt. 5 & 6 and differed from the previous alternatives by the use of a rope pump operated by animal power. The alternative scenario four and ten (Alt. 4 & 10) were the third best performing and involved the use of recommended fertilizers and deep tillage combined with the irrigation of onions using a rope pump operated by hand and solar motor. The worst performing scenarios were the baseline and alternative scenario one (Alt. 1), which uses the pulley to irrigate onions and current tillage for grain crops. Of the best performing scenarios (Alt. 7 & 8), alternative scenario 8, in which a rope & washer pump operated by a gasoline motor is used to irrigate onions, generated the highest profit for farmers. While the irrigation water requirements for 787 ha of irrigable land for onions are covered by the use of a rope & washer pump operated by a gasoline motor, the rope pump operated by animal power can cover the majority of the total irrigable land but with lower entry and operational costs compared to the gasoline motor. The simulation results show however that investing in the gasoline motor and animal power will generate more profit for the farmer. As for nutrition, deficiencies observed for fat, calcium and vitamin A will require the family to consume more diverse food items either through farming or purchase.

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Appendix A

Water Lifting Technologies (WLT)

Pulley/bucket system

Photo 1&2: ILSSI site/Bahir Dar-Ethiopia-2015

Rope and washer pump operated by hand

Rope and washer pump operated by a horse

Note:

Photo 3: ILSSI site /Adami-Tulu Ethiopia, 2015

Photo 4: http://www.ropepumps.org/horse.html

Photo 5: http://www.ropepumps.org/solar.html

Photo 6: http://www.ropepumps.org/motor.html

Rope and washer operated by solar energy

Rope and washer operated by motor