Profitability and Economic Feasibility Analysis of Small Scale Irrigation Technologies in northern Ghana

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Abstract

Small-scale irrigation (SSI) technologies can be a useful tool not only to increase crop productivity and income but also to mitigate against climate variability in Ghana given the recent frequent dry spells. Profitability and economic feasibility of investing in the SSI technologies are analysed using a farm simulation model (FARMSIM) and based on farm-plot level data on selected SSI technologies piloted in northern Ghana under the Innovation Lab for Small Scale Irrigation (ILSSI). The aim is to identify profitable and economically feasible sets of '*crop type–SSI technology*' combinations that would prove viable in "real world" farm conditions. Four dry season irrigated cash crop (corchorus, onion, and amaranths) grown under four SSI technologies (pump-tank-hose, watering can, and rain/roof water harvesting and drip irrigation) were considered. Results showed that rainwater-harvesting using poly tank storage and a drip system is not economically feasible at the current yield level and market prices of irrigated cash crops in northern Ghana. SSI technology options using river water or shallow wells with motorized pumps or watering cans were profitable. The watering can is relatively more profitable than motorized pumps because of fuel and upfront investment costs in pumps. However, affordable credit schemes could mitigate the cost constraint to afford motor pumps and enable smallholders to participate in market-oriented production.

Key words:

Economic analysis, ILSSI, Northern Ghana, Profitability, Small scale irrigation, Smallholders

1. Introduction

The absence or limited access and use of appropriate agricultural technologies have led in part to the lack of increases in productivity and persistent food insecurity in developing countries (ITAS, 2009). National governments, international agencies and several development organizations have attempted to make agriculture more productive and profitable by introducing agricultural technologies but with modest results (Yengoh et al., 2009). Several factors have contributed to low rate or lack of adoption of new agricultural technologies in developing countries including the limited access to the technologies. Even where these technologies have been adopted at a smaller pilot communities, the dissemination to a larger segment of the population has failed in many cases.

The Ministry of Food and Agriculture (MoFA) of Ghana promotes small-scale irrigation (SSI) as a climate variability adaptation measure in response to the declining rainfall and increasing intermittent dry spells during the rainy season cropping period (MOFA, 2014). SSI is one of the three principal irrigation systems recognized in national irrigation development policy[1] in Ghana. According to the policy, SSI is practised by individuals who cultivate a land area of up to about 0.5 ha or more, using simple structures and equipment such as buckets, motorised pumps, hoses, and watering cans for water lifting, conveyance and application; water sources include small reservoirs, shallow groundwater, rivers and wastewater. In short, SSI is an irrigation system practiced on small plots using a level of technology that an individual farmer can effectively control, operate and maintain (Carter and Howsam, 1994; Namara, 2010).

SSI continues to expand despite low government support, and limited input from technical or extension services in Ghana (Namara, 2010; Giordano et al. 2012; Namara et al., 2014). SSI employs 45 times more people and covers 20 times more land area than large-scale public irrigation schemes. As at 2010, an estimated 185,000 ha was under SSI, benefiting 500,000 smallholder farmers Evans et al. (2012) and FAO (2012) projected that use of motorized pumps in SSI could benefit up to 730,000 households and irrigate 584,000 ha in Ghana. Similar projections suggest that the use of small reservoirs could benefit about 163,000 households and irrigate 163,000 ha in Ghana. In the northern regions, SSI water application is mainly watering cans, handheld hose, and diesel or petrol-powered motorized pumps, although drip and sprinkler irrigation are increasing (Drechsel et al. 2006; 2007). Potential also exists in shallow groundwater using various water lifting, conveyance and application technologies (Barry et al. 2010; Namara et al. 2014), as well as improved utilization of multi-purpose small reservoirs.

The rate of adoption of SSI is likely to increase. The demand is growing for vegetables and fruits with increases in income and changing diets of the growing middle-income consumers in urban areas, providing a business opportunity for small-scale irrigators. Different out-grower models are also feasible for more small-scale irrigators to become involved in market-oriented production. However, sustainable adoption and scaling of various SSI technologies depend on the biophysical conditions and economic feasibility along various value chains. At present, little evidence is available on socio-economic, nutritional and technical factors that could promote or impede sustainable intensification utilizing SSI in northern Ghana. Understanding these factors can enable appropriate support to improve the scaling pathway for SSI and the livelihoods of smallholder farmers. This includes: : (i) identification of ways to improve water use and

[1]www.mofa.gov.gh/site/wp.../07/GHANA-IRRIGATION-DEVELOPMENT-POLICY1.pdf. The other two irrigation categories comprise of *formal irrigation* (one that is reliant on some form of permanent irrigation infrastructure funded by the public sector and *large scale commercial* irrigation system.

management for farmers adopting SSI technologies; (ii) provision of evidence for informed investment decisions by farmers and other actors in value chains that utilize SSI; (iii) identification of promising technologies and crop types with high financial returns that improve livelihoods and food security for smallholder farmers; and (iv) understating the economic, health/nutrition impacts and other benefits of scaling up of the SSI technologies at various scales.

This paper seeks to contribute to filling the gap in knowledge in the economic and nutritional effects of SSI technology adoption by smallholder farm households. The study also aims to provide evidence on potential returns to investment in various SSI technologies by smallholder farmers and others interested in the sector. Using primary farm-plot level data on selected SSI technologies piloted in two communities and secondary data from relevant sources such as MoFA and GIDA and applying FRAMSIM as an analytical model, this study aims to identify profitable and economically feasible '*crop type–SSI technology*' combinations that would prove viable in "real world" farm conditions in the study area. The findings provide evidence on the economic potential and household level nutritional effects of investing in the SSI technologies among smallholder farm households in northern Ghana and other countries/regions with similar environmental and socio-economic settings.

2. Water sources for SSI in northern Ghana

Studies show that there is high potential for SSI in northern Ghana. Northern Ghana is drained by the Volta River system consists of White and Black Volta Rivers, the Oti and Darka Rivers. In the Volta Basin, water for irrigation is sourced from rivers, groundwater, and stored water in natural and built infrastructure or reservoirs (Johnston and McCartney, 2010; Payen et al., 2012). In northern Ghana, there are large and medium reservoirs for public sector managed irrigation schemes at Tono, Vea, Golinga, Bontanga and Libga with storage capacities ranging from 5.9 to 93 Mm^3. Additionally, there are more than 500 small reservoirs and over 6280 boreholes managed by communities and smallholder farmers (Johnston and McCartney, 2010; GIDA, 2011). Water is also stored on-farm in ponds and wetlands (McCartney et al., 2013). In many areas in northern Ghana, shallow groundwater is the farmers' preferred water source (Molden, 2007; Namara et al., 2011). Permanent shallow wells are widespread in several communities (Lamptey et al., 2009; Payen et al., 2012). Small reservoirs and dugouts are in high demand because they support multiple livelihood strategies, including irrigation, livestock production, fisheries and brick fabrication (van de Giesen et al. 2002; Blench, 2007; Birner, 2008; Namara et al. 2010).

Shallow ground water - A number of studies have assessed the potential for shallow groundwater development for SSI in northern Ghana (Drechsel and Keraita, 2014; Namara et al. 2014; Barry et al., 2010). The studies estimated that the groundwater potential for irrigation in the Upper East region that can be stored annually in the underlying aquifer was approximately 3.7×10^8 m^3, which is by far more than what is actually applied for irrigation annually (2 litres/day/m^2 at planting stage and 5 litres/day/m^2 at flowering stage). Forkuor et al. (2013) assessed the suitability of groundwater development for small-scale irrigation over an area covering 108, 671 km^2 in northern Ghana. Their analysis showed that there is a high potential for development of groundwater in the northern Ghana as about 70% of the area was found to have high to moderate groundwater availability, while 83% has high to medium groundwater accessibility.

Small reservoirs and dugouts - Northern Ghana is endowed with a number of multi-purpose small reservoirs (Fig. 1). These reservoirs could be better developed and utilized for small scale irrigation. Good water storage infrastructure combined with SSI technologies will allow farmers to practice dry season farming and supplementary irrigation during dry spells in the rainy season, thereby avoiding crop failure and allowing higher yields compared with sole reliance on rainfall. Evans et al. (2012) and FAO (2012) projected that use of small reservoirs could benefit about 163,000 households and irrigate about 163,000 ha in Ghana. Small reservoirs and dug-outs are typically owned and managed communally through water users' associations (WUAs), though in some cases individuals own and manage (Namara et al., 2010). In the Upper East region several small reservoirs and dugouts were rehabilitated by various agencies and programmes such as the Ghana Social Opportunities Project (GSOP) and the World Food Programme (WFP).

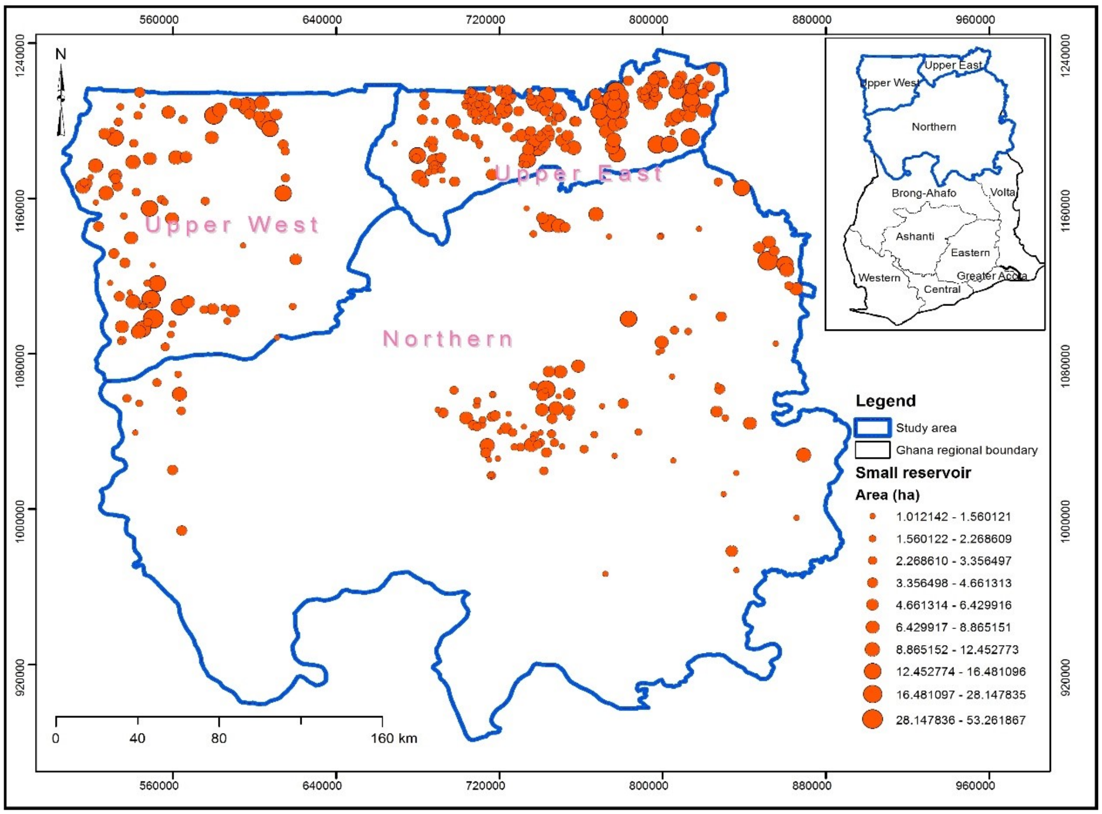

Figure 1. Distribution of multi-purpose small reservoirs in northern Ghana

River-based SSI schemes - the Northern Rural Growth Programme (NRGP) and Ghana Social Opportunity Project (GSOP) have rehabilitated small scale irrigation infrastructure and introduced water lifting technologies (Fig. 2) . For example, the White Volta River provides a perennial source of water that could be used for year-round irrigated agricultural production by small holders. The NRGP invested in small scale irrigation development in Northern and Upper East regions to enable water lifting from the river. Specifically, the NRGP rehabilitated five river-based irrigation schemes in the two regions which were expected to irrigate a total area of 778 ha.

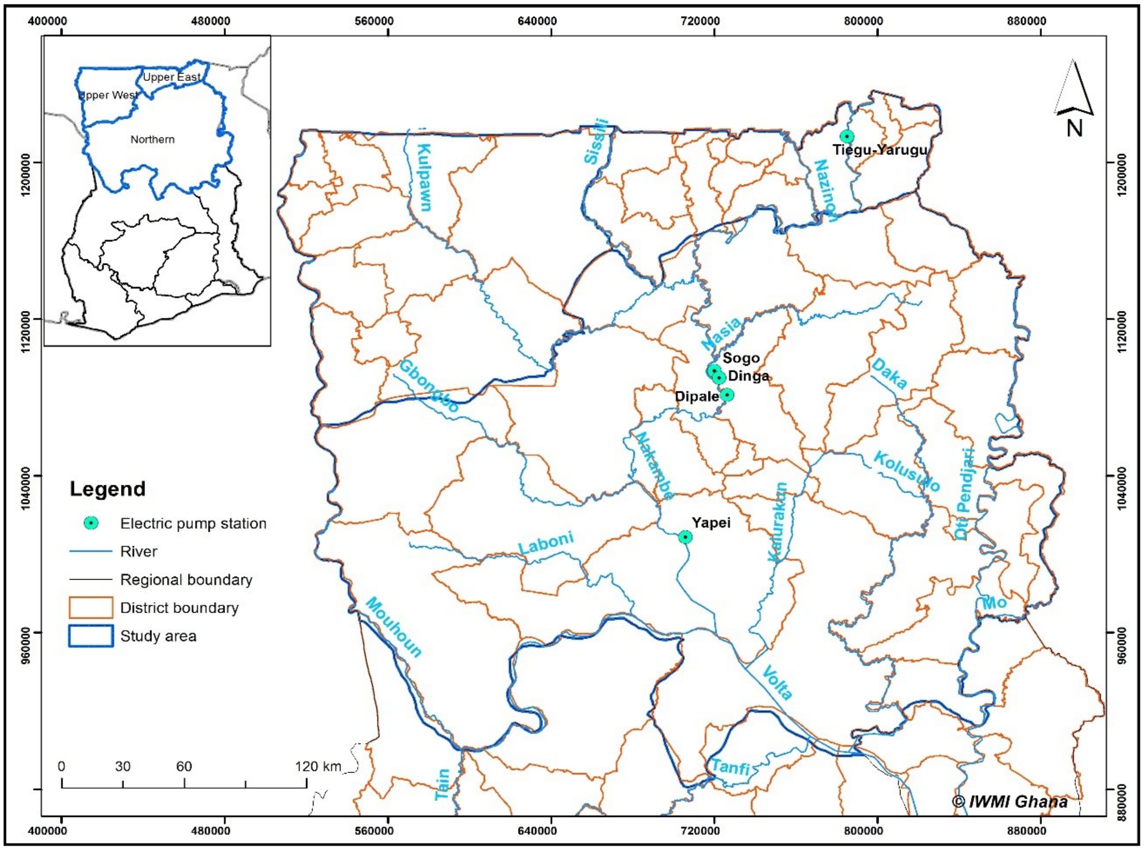

Figure 2. Network of major Rivers in northern Ghana

Floodplains – Northern Ghana is endowed with large floodplains created by several tributaries of the Volta River. The potential exists for flood recession agriculture in the floodplains due to seasonal flooding that occurs around July-September. These extensive floodplains with high natural fertility are suitable for cultivation of a variety of crops such as tomatoes, onions, pepper, and cowpea (Donkoh at al., 2013; Obeng, 2000; Sidibe et al., 2016). This is an agricultural practice that uses residual soil moisture and nutrients left by receding flood water with or without supplementary irrigations to grow crops. A recent survey of nine communities in Upper East and Northern Regions of Ghana revealed that more than 60% of households in the floodplain areas practice flood recession agriculture or FRA (Balana et al., 2015). However, residual soil moisture is often insufficient for a number of FRA crops and hence supplementary irrigation is needed, but farmers buy irrigation equipment and kits.

The key challenges that could impede adoption and upscaling of SSI in northern Ghana include: (i) most farmers in northern Ghana cannot afford the upfront investment cost of purchasing irrigation equipment such as pumps and irrigation kits. At the same time, innovative leasing and financing schemes that can allow them to hire or own the equipment are not in place; (ii) SSI becomes expensive for smallholders due to high fuel and maintenance costs (de Fraiture and Giordano, 2014; Giordano and de Fraiture, 2014; Namara et al. 2014); (iii) farmers lack information and knowledge about appropriate irrigation equipment and irrigation water use efficiency. The ILSSI project aims to tackle some of these challenges through piloting SSI technologies and providing technical and material support to smallholders in selected communities in the northern Ghana.

3. Data and study area

Two main datasets were used in this study: field data collected on farms to define the input for the alternative farming technologies and a household survey to define the baseline scenario. The data used in the study to define the alternative SSI technologies were collected under the Innovation Lab for Small Scale Irrigation (ILSSI[2]) project. ILSSI aims to investigate and understand the technical and socio-economic factors, constraints and opportunities of SSI technologies towards achieving sustainability and efficiency in resource utilization (water, land and other resources) and enhance the livelihoods of smallholder farmers. The data came from four sources:

(i) Plot level production (inputs and outputs) data collected by the University of Development Studies (UDS) over a period of one dry season in 2016-17 (with two cropping cycles for some crops);

(ii) Farm level inputs and outputs data collected by IWMI researchers through direct interviews of pilot farmers in the field in March 2017;

(iii) Two household surveys collected in 2014 and 2015 in Ghana by IFPRI. The first survey was carried under the Ghana Africa RISING Baseline Evaluation Survey (ARBES) (IFPRI, 2015)[3] while the second was collected under the ILSSI project. Both of them were used to define the baseline scenario against which small-scale irrigation technologies were evaluated

(iv) Secondary data obtained from sources such as the Ministry of Food and Agriculture (MoFA - Ghana); Ghana Irrigation Development Authority (GIDA); agricultural inputs dealers in the study area and local market information, e.g., seasonal price data in the nearest market centers to the production sites.

Figure 3 shows the location of ILSSI field interventions sites in Ghana, which are located within the Feed the Future and the SADA[4] zone. Table 1 summarizes the SSI technologies, communities and crop types ILSSI has piloted in farmers' fields. This paper focuses on three SSI interventions in two sites in northern Ghana (Zanlerigu and Bihinayiili communities).

[2] Visit the project website at: http://ilssi.tamu.edu/. ILSSI is an action-oriented, farmer-centered research project supported by the Feed the Future (FtF) program through USAID and implemented in Ghana, Ethiopia, and Tanzania.
[3] https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/QUB9UT
[4] SADA: Savannah Accelerated Development Authority. The Government of Ghana has mandated SADA to coordinate and facilitate economic development in northern Savannah ecological zone.

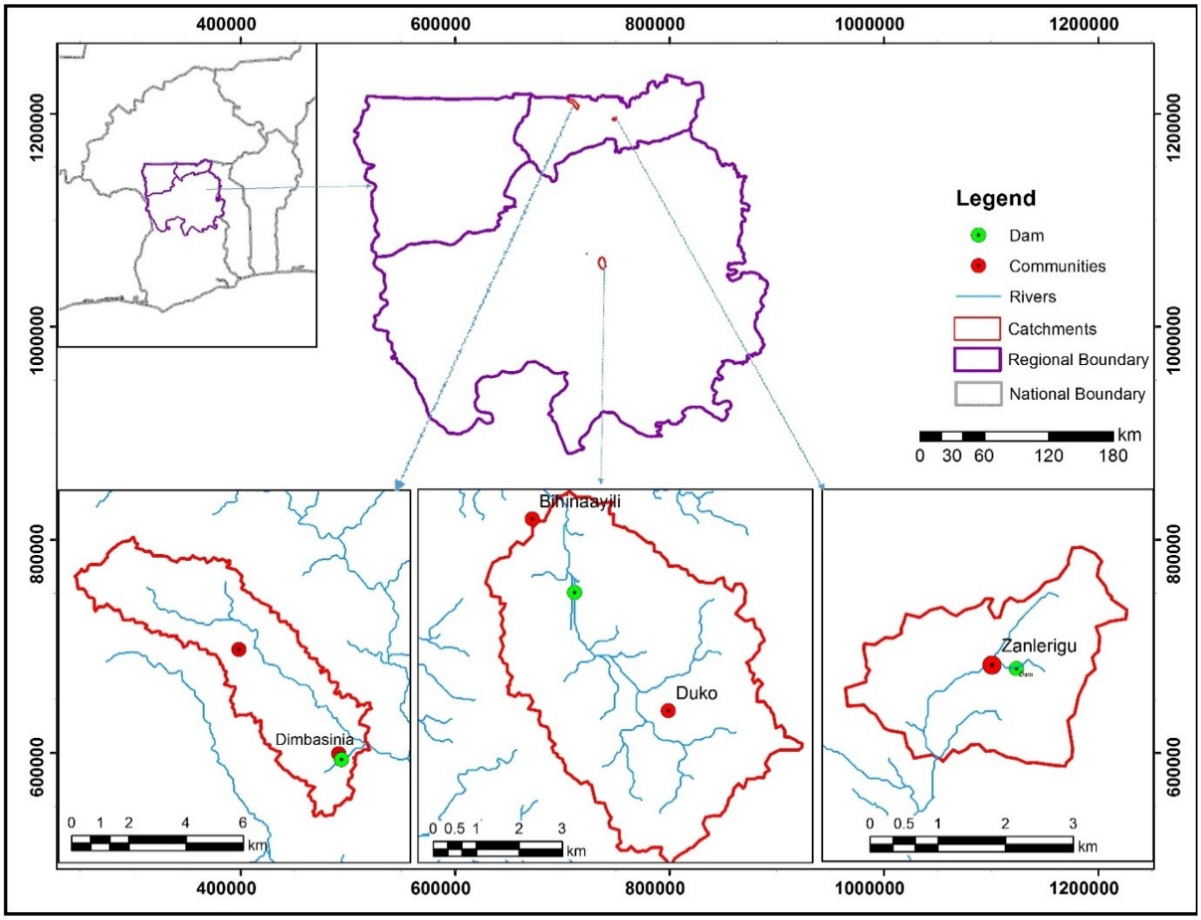

Figure 3: Map of the study communities

Table 1. Communities, water sources and project interventions

Community	Water source	SSI Interventions			Crop type	No. of farmers
		Water lifting	Water storage	Water application		
Bihinaayili	Runoff/ stream	Motorized pump	Overhead tanks	hose	Corchorus (*Corchorus olitorius)*	8
		Watering can	Canal/ trench	Watering can	Corchorus (*Corchorus olitorius)*	8
Zanlerigu	Shallow wells	Motorized pump	Overhead tanks	hose	Onion and amaranth (*Amaranthus candatus)*	8
	Shallow wells	Watering can	Shallow well	Watering can	Onion and amaranth (*Amaranthus candatus)*	8
	Rainwater	n/a	Overhead tanks	Drip system	Cowpea	4
	Rainwater	n/a	Overhead tanks	Hose	Cowpea	1

4. Methods and approach

Agriculture is a relatively high risk and uncertain enterprise due to a number of risky factors related to the agricultural business such as production, marketing and finance (Hardaker, et al., 2004; Qasim, 2012). Some of the risk and uncertainty components surrounding the production and marketing processes are related to unpredictable weather variation (drought, frost, flood, and wind storm), input quality, pest and disease attacks, price fluctuations, new technology failure, and changes in government policies. There is therefore a need to explicitly take into account risk in evaluating the economic impact of agricultural technologies such as the SSI technologies. Farm modeling using a Monte Carlo simulation model is one of many approaches that can help in studying the economic feasibility of adopting SSI technologies on a farm (Richardson et al., 2007).

4.1 FARMSIM model description

The farm simulation model "FARMSIM" is a Monte Carlo simulation model that simultaneously evaluates a baseline and alternative technologies for a farm. The model is programmed in Microsoft ® Excel and utilizes the Simetar© add-in to estimate parameters for price and yield distributions, simulate random variables, estimate probability distributions for key output variables (KOVs) and rank technologies (Richardson et al., 2006)[5]. FARMSIM is programmed to recursively simulate a five year planning horizon for a diversified crop and livestock farm and repeats the five-year planning horizon for 500 iterations[6]. A new sample of random values is drawn to simulate each iteration. After simulation, the resulting 500 values for each of the KOVs defines the empirical probability distributions for comparing the base and alternative farming technologies or interventions. By comparing the probability distributions for the base and alternative technologies, decision makers can quantitatively analyse the probable consequences of introducing alternative technologies.

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

4.2 Economic and nutritional assessment

The economic feasibility assessment of the selected SSI technologies is based on decision criteria of cost-benefit analysis (CBA). CBA is an applied economic tool often used to guide resource allocations or investment or policy decisions. In situations where benefits and costs of an action spread over time, decisions are based on comparing the present values of benefit and cash flows. The net present value (NPV), internal rate of return (IRR), and the benefit-cost ratio (BCR) are the key criteria used in this study

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

[6] Extensive testing with the Latin Hypercube sampling procedure in Simetar has shown that a sample size of 500 iterations is more than adequate to estimate a probability distribution for KOVs in a business model with more than 100 random variables.

to assess the SSI technologies that involve upfront investment in terms of water storage facility and pumping machines.

NPV is defined as the difference between the sum total of the present value of benefit streams and that of cost streams over the life of the project. Equation 1 presents the mathematical expression of the NPV computation. Projects with positive NPV are accepted while projects with negative NPV are rejected.

$$NPV = \frac{\sum_{t=0}^{T} B_t}{(1+d)^t} - \frac{\sum_{t=0}^{T} C_t}{(1+d)^t} = \sum_{t=0}^{T}\left[(B_t - C_t)(1+d)^{-t}\right] \text{--- (1).}$$

$B_t =$ Value of benefit streams in period 't' (i.e., cash flow benefits at each period)

$C_t =$ value of cost streams in period 't' (i.e., cash flow of costs at each period)

$d =$ discount rate

$t =$ time periods (usually in years) (($t =$ 1, 2, ... T) where *'T'* is the life span of the project.

The IRR is defined as the discount rate that need to be applied to generate a NPV value of zero. In a business world, IRR computes the break-even rate of return showing the discount rate, below which an investment results in a positive NPV. Using the IRR criterion, accept a project if its IRR exceeds the cost of capital (i.e., the return from the capital if invested elsewhere) and reject if the IRR is less than the cost of capital.

Benefit-Cost Ratio (B/C) is the ratio of the present value of the benefits to the present value of the costs. If this ratio is greater than one, the project is recommended. This is an equivalent condition to the NPV criteria where if the discounted present value of the benefits exceeds the discounted present value of the costs then the project is worthwhile.

Alongside economic variables estimation, nutrition variables are evaluated and compared to daily minima requirements per adult equivalent to determine excess or deficiency in nutrients intake. In the nutrition simulation section of the FARMSIM model, the total kilograms of each raised crop consumed by the family plus the kilograms of purchased foodstuffs are multiplied by their respective nutrient scores to calculate total calories, protein, fat, calcium, iron and vitamin A from the food stocks. Similar calculations are made to simulate the nutrients derived from consuming cattle, oxen, milk, butter, chickens, eggs, mutton, lamb, nannies, and pig meat. Total nutrients consumed by the family from all sources, including donated food, are summed across plant and animal food stocks and compared with minimum daily recommended amounts for adults based on the FAO minimum requirements standards (FAO, 2001; FAO, 2010). For the nutrition variables simulation, the formula to simulate protein intake for instance for the farm family is as follows (eq. 2):

$$\tilde{P}rotein_t = [\sum_i (Family\ Consumption_{it} + Purchased\ Crop_{it}) *$$

$$Grams\ of\ Protein\ /Unit\ of\ Crop\ i] + [\sum_j\ (Family\ Consumption_{jt} + Purchased$$

$$Livestock\ Product_{jt}) * Grams\ of\ Protein\ /Unit\ of\ Livestock\ Product_j]\text{---------- (2)}$$

The protein equation is repeated for each of the remaining nutrient categories of: calories, fat, iron, calcium and vitamin A. Probability that the farm household's nutritional intake exceeds the FAO recommended daily requirements is calculated annually over the 500 iterations for each of the six nutrient categories to determine the probability that a particular nutrient is not deficient. The formula for each nutrient is the same as the equation for protein (eq. 3).

$$P(Protein_t) = \sum_s \, (1 \; if \; Protein_{ts} \, / \, 365 > Daily \; Minimum \; Req, 0 \; else) \, / \, 500 \ldots\ldots\ldots\ldots\ldots (3)$$

4.3 Stochastic simulation process

Simulation has become an important tool for risk analysis and a decision aid tool to manage risk for farmers and policy makers. Part of the process to determine the level of risk and its mitigation is the simulation of the stochastic variables that bear most of the risk: prices and yields. A procedure was developed to simulate stochastic variable in farm-level models used in policy and strategic planning analyses (Richardson, Klose and Gray, 2000, p.2). Stochastic annual output prices for crops and livestock are simulated using multivariate empirical (MVE) probability distributions estimated from historical data. Stochastic annual crop yields are simulated from multivariate empirical probability distributions estimated using 32 years of crop yields generated by APEX (Agricultural Policy / Environmental eXtender) (Williams et al., 1998). Selected SSI technologies piloted in the ILSSI project are simulated by APEX using the same historical weather data and plant growth parameters consistent with the assumed technologies so the only difference between the yield distributions is the technology package.

The baseline and alternative technology scenarios are simulated by FARMSIM using the same equations so the only difference in the economic and family nutrition outcomes are due to the technology differences. The random crop yields are simulated using the same stochastic uniform standard deviates to insure that the weather risk for a crop under the base and alternative technology scenarios are identical. The same stochastic prices for crops are used for both scenarios, unless the alternative scenarios call for a different marketing program which shifts the price distribution to a higher level. Since the base and alternative models use identical equations, the decision maker can be assured that the differences in the KOVs are due to the differences in the two farming systems and their assumed yield distributions. The FARMSIM model has four major components: crops, livestock, nutrition, and financial (see details on the components and their equations in Richardson and Bizimana, 2017.

5 Scenarios analysis and ranking

5.1 Base and alternative farming technology scenarios

The data is input into the farm simulation model (FARMSIM) in parallel where for each input variable the user must provide information for the current (baseline) and alternative farming system (scenario) (see flowchart in Appendix A). The model is designed so the user can enter complete data sets for the baseline and up to 21 alternative scenarios. Due to the importance of irrigation in crop and livestock production in Ghana, SSI technologies are discussed using two case studies from the Bihinayilli and Zanlerigu communities in Northern and Upper East regions of Ghana. SSI technologies enable smallholder farmers to have dry season crops that can provide improved nutrition and generate income with less risk, provided that, there is a sustainable source of water and application technologies for the land area to be irrigated.

Household survey information used to establish the baseline conditions shows that the major crops grown in wet season in Bihinayilli/Duko community are maize, yam, rice, soybean and sorghum, while in

Zanlerigu/Shia community[7], maize, millet, rice and groundnuts are the predominant rain-fed crops. Vegetables such as corchorus, amaranth and onion considered in this study, are grown on a limited land either as rain-fed or with very minimal irrigation. Only about five percent of the household surveyed indicated to irrigate their crops using mainly water from river diversion. The survey shows that agricultural inputs (fertilizer, irrigation, improved seeds) were used at a very minimal level in Zanlerigu while quantities of fertilizers for instance in Bihinayilli were slightly higher for an average household. The survey information shows as well that most of the households used stored seeds from the previous harvest for the following planting season and that the use of chemicals was limited. It was also noted that the level of farm labor hiring for agricultural production was low since family members performed most of the agricultural tasks. It is worth mentioning that, the use of actual crops to feed animals is not common as most of the animal feed comes from crop residues. To capture the economic impact of adopting SSI technologies the input data information (yields, input costs, consumption, cropping area) for the rain-fed crops was kept constant for the baseline and alternative farming scenarios.

In alternative scenarios, irrigation water drawn from shallow wells, ponds (dugouts) and river/stream using different water lifting and application methods (watering can, hose, drip and motor pumps), allowed to grow vegetables (corchorus, amaranth and onion) on larger areas during the dry season (double cropping on the same land). Input costs for labor and agricultural inputs, as well as crop yields increased for the irrigated crops in alternative scenarios. It is expected that the yields and profit differences between the baseline and the alternative scenarios are mainly due to fertilizer and irrigation applications (cost of energy and labour inputs).

Three scenarios that comprise a baseline and two alternative scenarios were considered for both the Bihinayilli and Zanlerigu sites summarized below.

Bihinayilli site:

- Baseline: current fertilizer + no or minimal irrigation
- Alt.1 (Watering can): irrigate vegetables (corchorus) with watering can + recommended fertilizer
- Alt.2 (Motorized pump): irrigate vegetables (corchorus) with diesel pump and hose + recommended fertilizer

Zanlerigu site:

- Baseline: current fertilizer + no or minimal irrigation
- Alt.1 (Watering can): irrigate vegetables (onions and amaranth) with watering can + recommended fertilizer
- Alt.2 (Motorized pump): irrigate vegetables (onions and amaranth) with diesel pump and hose + recommended fertilizer

[7] Due to the lack of baseline household data on Bihinayilli and Zanlerigu, available household data on Duko and Shia communities which are located in same watershed as the target communities, were respectively used to characterize the baseline conditions.

5.2 Technology scenario ranking

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

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

5.3 Micro and macro level assumptions

First, to show the full potential economic and nutrition impact of adopting new technologies, we assumed that the alternative farming technologies (alternative scenarios) simulated in this study on crop production and use of water lifting technologies were adopted at 100 percent. Although the data used as input for the alternative scenarios were collected on a few households that participated in the SSI farm trials, it is assumed that the adoption will spread across the entire village as their neighbors witness the positive outcome of adopting these SSI technologies. The concern for farmers to acquire the irrigation tools such as pumps due to the high capital cost was partially addressed by making available, to farmers, loans to purchase the tools through the ILSSI project and by encouraging them to purchase and share these tools as a group of a few households.

Second, since the farmer's profit mainly depends on the amount of crop and livestock (including livestock products) sold at the markets, accessibility to markets by the farmers is of great importance. The markets were assumed to be accessible and function competitively with no distortion where the supply and demand determine the market prices. Accessibility to markets and competitive market prices depend mainly on the existence of road and market infrastructure in both communities of Bihinayilli and Zanlerigu. Survey data in Bihinayilli show that farmers reported on average that it took them about 30 min to get to a local market but the majority of them (60%) indicated to sell their produce on farm. Zanlerigu community is located close to the main regional marketing center of Bolgatanga town (capital of Upper East Region).

6 Results and discussion

The baseline scenario considers minimal irrigation based on the household survey information while the alternative scenarios considers the application of irrigation water to grow onions, amaranth and corchorus during the dry season using a water can or diesel pump system. The two alternative scenarios (Alt. 1 and Alt. 2) in both sites are respectively associated with the use of a water can and diesel pump in adequate irrigation conditions for optimal growth of onions, amaranth and corchorus. The irrigated crops were well adequately fertilized with urea and DAP for all alternative scenarios.

6.1 Bihinayilli site

NPV, NCFI or net profit and B/C ratio are used to evaluate the farm profitability of SSI technologies in Bihinayilli community.

The simulation results for NPV, which assesses the long-term feasibility of an investment, shows positive average NPV values for all the scenarios over the 5-year forecast period. Alt. 2 associated with the use of a diesel pump has the highest NPV value followed by Alt. 1 that involves the use of a watering can to irrigate corchorus (Table 2). The net cash farm income (NCFI) or net profit indicates similar results where the profit under Alt. 2 is respectively 2 and 5 times higher than the profit recorded under the watering can and the baseline scenarios. The probability distribution of the NCFI illustrated by the cumulative distribution function (CDF) shows as well the superior performance of Alt. 2 associated with the use of a diesel pump in irrigation of corchorus in Bihinayilli (Figure 4).

The benefit-cost ratio of the alternative scenarios compared to the baseline (B/C is based on the present value of their difference), show that both Alt. 1 and Alt. 2 have positive and strictly greater than one B/C ratios of 2.7 and 2.6 respectively (Table 2 and Figure 5). These ratios confirm as well the profitability of the alternative scenarios (B/C>1). Notice that, even though Alt. 2 profit is two times greater than Alt.1, the B/C value of Alt. 1 (Watering can) is greater than the B/C ratio of Alt. 2 (Diesel pump). This highlights the higher investment cost in diesel pump compared to watering can, which reduces the return on investment. It is worth mentioning that higher NPV and profit values from Alt. 2 are associated with the expansion of irrigated land and the increase in production and sale of corchorus at the market.

Table 2. Economic and nutrition impacts of SSI in Bihinayilli community

	Baseline	Alt. 1--Watering Can	Alt. 2--Diesel-P	
Avg. values in GHc/hh in year 5				
Net present value	22,779	28,270	36,731	
Avg. net profit	1,270	3,229	6,283	
% change profit: Alt to Baseline		**154%**	**395%**	
Benefit-Cost Ratio: Alt/Baseline		**2.7**	**2.6**	
Averages daily nutrients in year 5				Min. required
Energy (calories/AE)	4620.0	4629.0	4652.0	1,750
Proteins (grs/AE)	93.5	94.1	95.6	41
Fat (grs/AE)	73.1	73.1	73.2	39
Calcium (grs/AE)	**0.18**	**0.24**	**0.37**	1
Iron (grs/AE)	0.012	0.012	0.013	0.009
Vitamin A (grs/AE)	**0.00002**	**0.00003**	**0.00003**	0.0006

Note:

- Baseline: No or minimal irrigation;
- Alt.1—Watering Can: Water Can used in optimally irrigated systems
- Alt.2--Diesel-P: Diesel pump used in optimally irrigated systems
- AE = Adult Equivalent
- For economic variables: numbers in green show increase while those in red show decrease
- For nutrition variables: numbers in red show quantities of nutrients intake < min. required

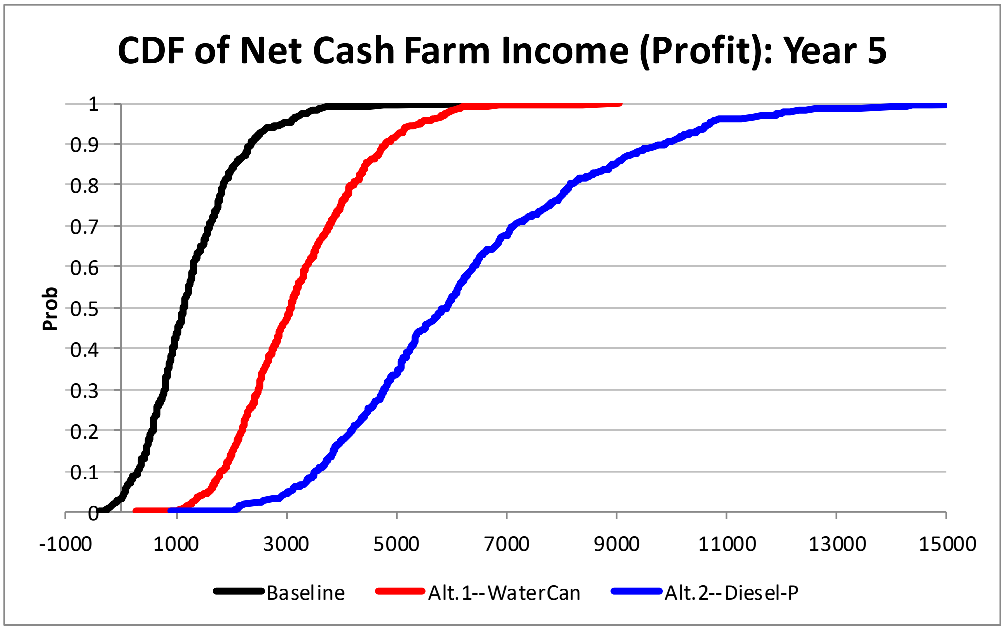

Figure 4. CDF of net cash farm income (profit) in year 5 in Bihinayilli

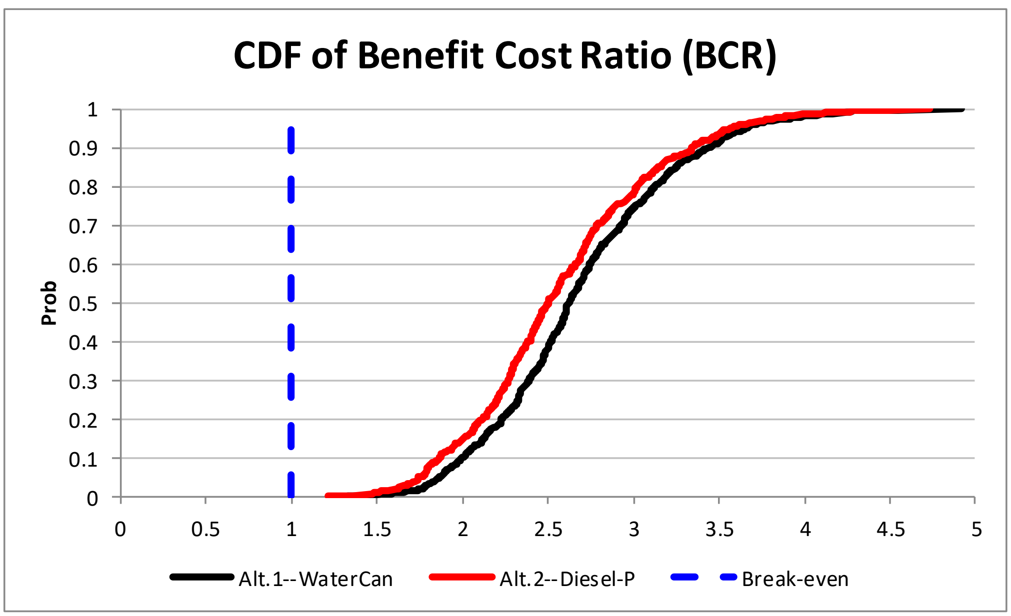

Figure 5. CDF of the benefit-cost ratio (BCR) for alternative irrigation technologies

The nutrition simulation results shows an improvement in terms of quantity intake, from the baseline to the alternative scenarios, for all nutrition variables (calories, proteins, fat, calcium, iron and vitamin A). Particularly, the caloric intake available for the household is relatively high (2 times higher than the average required) due to large contribution in calories by the soybean consumption. Despite the improvement from the Baseline to the Alternative scenarios, the nutrition results indicate deficiencies in calcium and vitamin A across all the scenarios. Although definitive nutrition assessment cannot be achieved using a few crops that are considered in the model, there is a possibility of using the profit from irrigated crops to purchase complementary food needed for nutrition supplements at the household level.

6.2 Zanlerigu site

Three key output variables (NPV, NCFI or net profit and B/C ratio) used to evaluate farm profitability of SSI technologies.

The simulation results for NPV show positive average NPV for all the scenarios over the 5-year forecast period. Alt. 2 associated with the use of a diesel pump has the highest NPV followed by Alt. 1 that involves the use of a watering can to irrigate onions and amaranth (Table 3).

The net cash farm income (NCFI) or net profit indicates similar results where the profit under Alt. 2 and Alt. 1 (Diesel pump and water can) are roughly 7 times higher than the profit recorded under the baseline scenario. The probability distribution of the NCFI (net profit) illustrated by the cumulative distribution function (CDF) shows as well the superior performance of Alt. 1 and Alt. 2 associated with the use of a water and a diesel pump in irrigation of onions and amaranth in Zanlerigu (Figure 6). However, it highlights as well the high cost of investment of the diesel pump, whose scenario shows a 10% probability of having a loss while the Baseline and Alt. 1 scenarios remain in the positive zone and profitable. Notice as well that the scenario associated with the use of a water can has a higher net profit than the diesel pump scenario under the 50% probability mark. In brief, the figure indicates that while Alt. 1 (use of a water can) and the baseline scenario have low potential of generating higher revenues/profit and present a low risk, Alt. 2 (use of diesel pump) has a higher potential of generating higher profit but at a relatively high risk.

The benefit-cost ratio of the alternative scenarios compared to the baseline, show that both Alt. 1 and Alt. 2 have on average B/C ratios that are positive and greater than one (2.8 and 1.4 respectively) (Table 3 and Figure 7). These average ratios confirm as well the profitability of the alternative scenarios (B/C>1), although Alt. 2 associated with the use of a diesel pump has a 23% probability of falling below one (B/C<1). Notice also that, despite Alt. 2 profit being slightly greater than Alt.1, the B/C value for Alt. 1 (Watering can) is greater than the B/C ratio of Alt. 2 (Diesel pump). This highlights again the relatively higher investment cost in diesel pump compared to watering can, which reduces the return on investment. It is worth mentioning that higher NPV and profit values from Alt. 2 are associated with the expansion of irrigated land and the increase in production and sale of onions and amaranth at the market.

Table 3. Economic and nutrition impacts of SSI in Zanlerigu community

	Baseline	Alt. 1-- Watering Can	Alt. 2-- Diesel-P	
Avg. values in GHc /hh in year 5				
Net present value	17,859	38,107	46,674	
Avg. net profit	824	5,559	5,841	
% change profit: Alt to Baseline		**574%**	**608%**	
Benefit-Cost Ratio: Alt/Baseline		**2.8**	**1.4**	
Avg. daily nutrients in year 5				Min. required
Energy (calories/AE)	1967	2239	2475	1,750
Proteins (grs/AE)	50.6	73.2	90.0	41
Fat (grs/AE)	**24.5**	**26.0**	**27.2**	39
Calcium (grs/AE)	**0.4**	2	3	1
Iron (grs/AE)	0.015	0.037	0.052	0.009
Vitamin A (grs/AE)	**0.00007**	**0.00017**	**0.00024**	0.0006

Note:

- Baseline: No or minimal irrigation
- Alt.1--Watering Can: Water Can used in optimally irrigated systems
- Alt.2--Diesel-P: Diesel pump used in optimally irrigated systems
- AE = Adult Equivalent
- For economic variables: numbers in green show increase while those in red show decrease

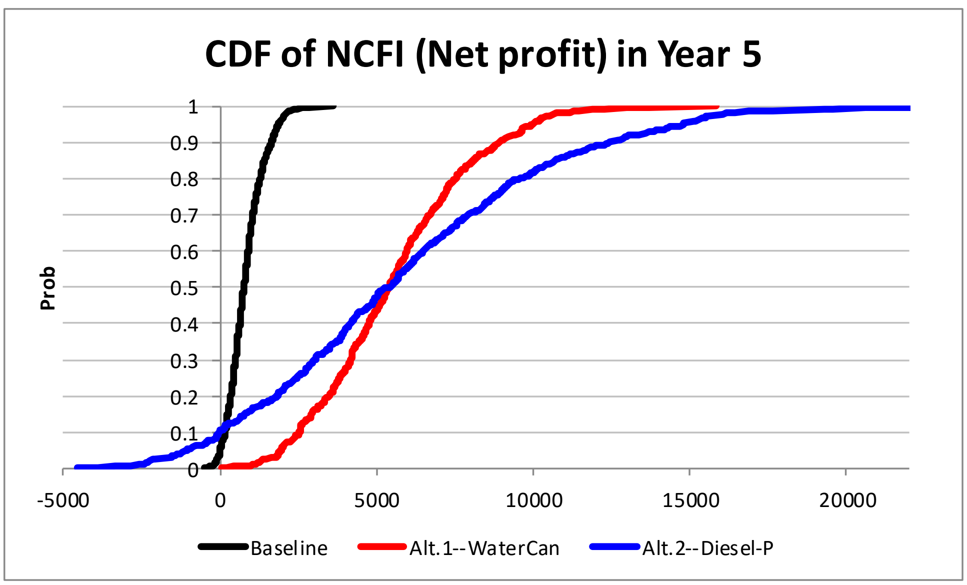

Figure 6. CDF of net cash farm income (profit) in year 5 in Zanlerigu

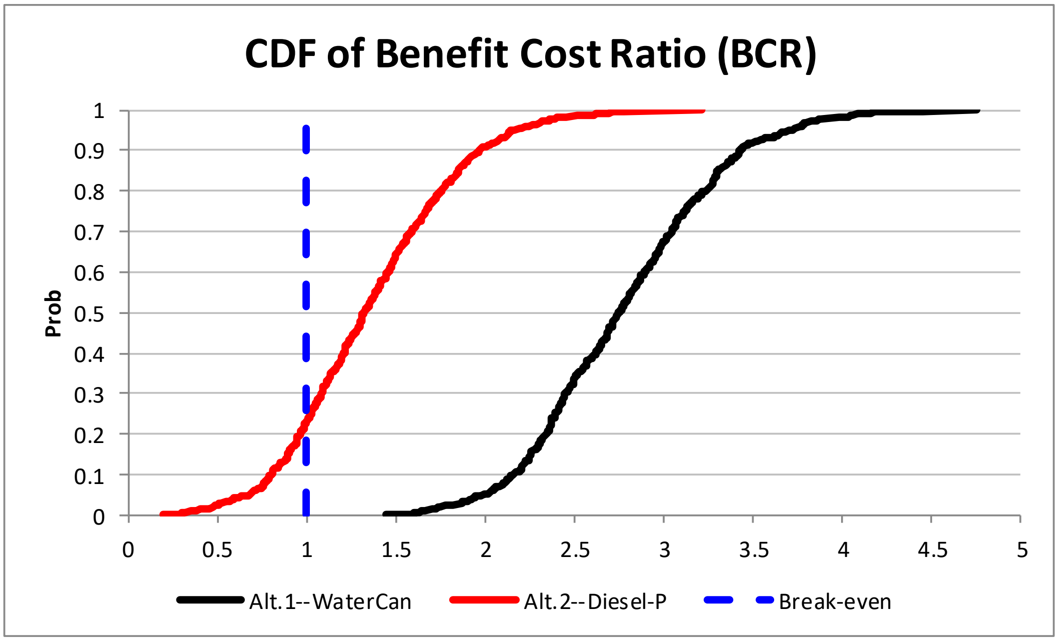

Figure 7. CDF of the benefit-cost ratio (BCR) for alternative irrigation technologies

The nutrition simulation results shows an improvement in terms of quantity intake, from the baseline to the alternative scenarios, for all nutrition variables (calories, proteins, fat, calcium, iron and vitamin A) (Table 3). Particularly, the calcium intake available for the household has dramatically increased from the baseline to the alternative scenarios (5 to 7 times) due to large contribution in calcium intake by amaranth consumption. An analysis of probability using the StopLigh chart (Figure 8) shows that there is a 99% chance for the Alt. 2 (Diesel pump) that the calcium intake will be higher than an upper cut-off value of 2.4 grs/AE. The Alt. 1 (Water can) shows on the other hand that there is 5% probability that the calcium intake will higher than 2.4 grs/AE while the Baseline scenario has zero probability of having the calcium intake greater than 2.4 grs/AE. Both the Alt. 1 and Alt. 2 have a sure probability of meeting and exceeding the minimum required for calcium which is normally deficient.

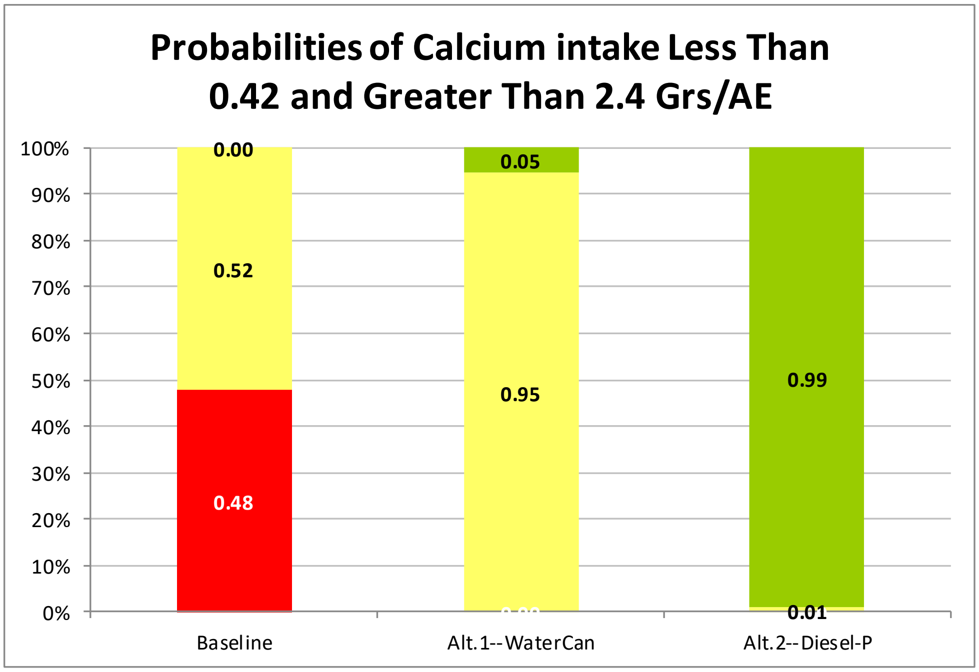

Figure 8. StopLight chart for calcium intake per Adult Equivalent in Zanlerigu

Despite the improvement from the Baseline to the Alternative scenarios, the nutrition results indicate deficiencies in fat and vitamin A across all the scenarios. Although definitive nutrition assessment cannot be achieved using a few crops that are considered in the model, there is a possibility of using the profit from irrigated crops to purchase complementary food needed for nutrition supplements at the household level.

7 Conclusions and recommendations

The purpose of this study was to evaluate the impacts of adopting small-scale irrigation technologies (increased fertilizers and irrigation) on farm profitability and household nutrition in Ghana. A baseline scenario with current fertilizer application rates and no or minimal irrigation was compared to two alternative scenarios where recommended fertilizers rates and various SSI technologies piloted to vegetable crops in Bihinaayili and Zanlerigu communities in northern Ghana. In Bihinayilli, corchorus was irrigated while in Zanlerigu, onions and amaranth received irrigation.

The preferred scenario, consisting of the application of recommended fertilizers in combination with the use of watering can or diesel pump to irrigate corchorus, onions and amaranth, generated the highest income and profits for the farm in Bihinayilli and Zanlerigu. Although in all the case studies the diesel pump generated the highest income, the cost-benefit analysis showed the watering can to provide more return on investment and a low risk. The baseline scenario was the least preferred of all three scenarios analyzed.

Nutrition levels improved significantly in the two alternative scenarios compared to the baseline scenario as a result of the improvements in crop yields due to the application of fertilizer and irrigation technologies. Noticeably the calcium intake available for household increased substantially in Zanlerigu due to the consumption of amaranth. However deficiencies in fat, calcium and vitamin A were observed in the two sites.

The results provide important decision support evidence for promoting SSI technologies (for adoption and upscaling). Comparison of the economic results on watering can and motorized pump technologies showed that watering can was relatively more profitable, though highly labor intensive. The variation in levels of profitability is mainly due to the cost of fuel and capital investment required to purchase pumps. Firstly, the high cost of borrowing in Ghana makes the upfront investment in irrigation technologies very expensive. This is supported by other studies that show smallholder farmers are credit-constrained in northern Ghana (Balana et al. 2016). Targeted assistance may be needed to ensure that smallholders at lower levels of economic status can access financing mechanisms on appropriate terms (Namara et al 2013)[8]. Secondly, alternative energy options, notably solar pumps, could be a promising option for smallholder farmers to reduce labor while decreasing reliance on fuel. Studies have shown that agriculture labor costs in Ghana are high, as is the opportunity cost of labor employed in agriculture in absolute terms, particularly as rural households increasingly depend on non-farm activities to boost income (Nin and McBride 2014). The upfront cost of solar pumps is again expensive in Ghana compared to fuel pumps, and may deter smallholder farmers from adopting solar-based irrigation technology, unless affordable credit or innovative loan schemes become available.

[8] The majority of farmers that adopt SSI technologies on their own are usually wealthier. See: R.E. Namara, G. Gebregziabher, M. Giordano, C. De Fraiture (2013). Small pumps and poor farmers in Sub-Saharan Africa: an assessment of current extent of use and poverty outreach. *Water International* 38(6): 827-839.

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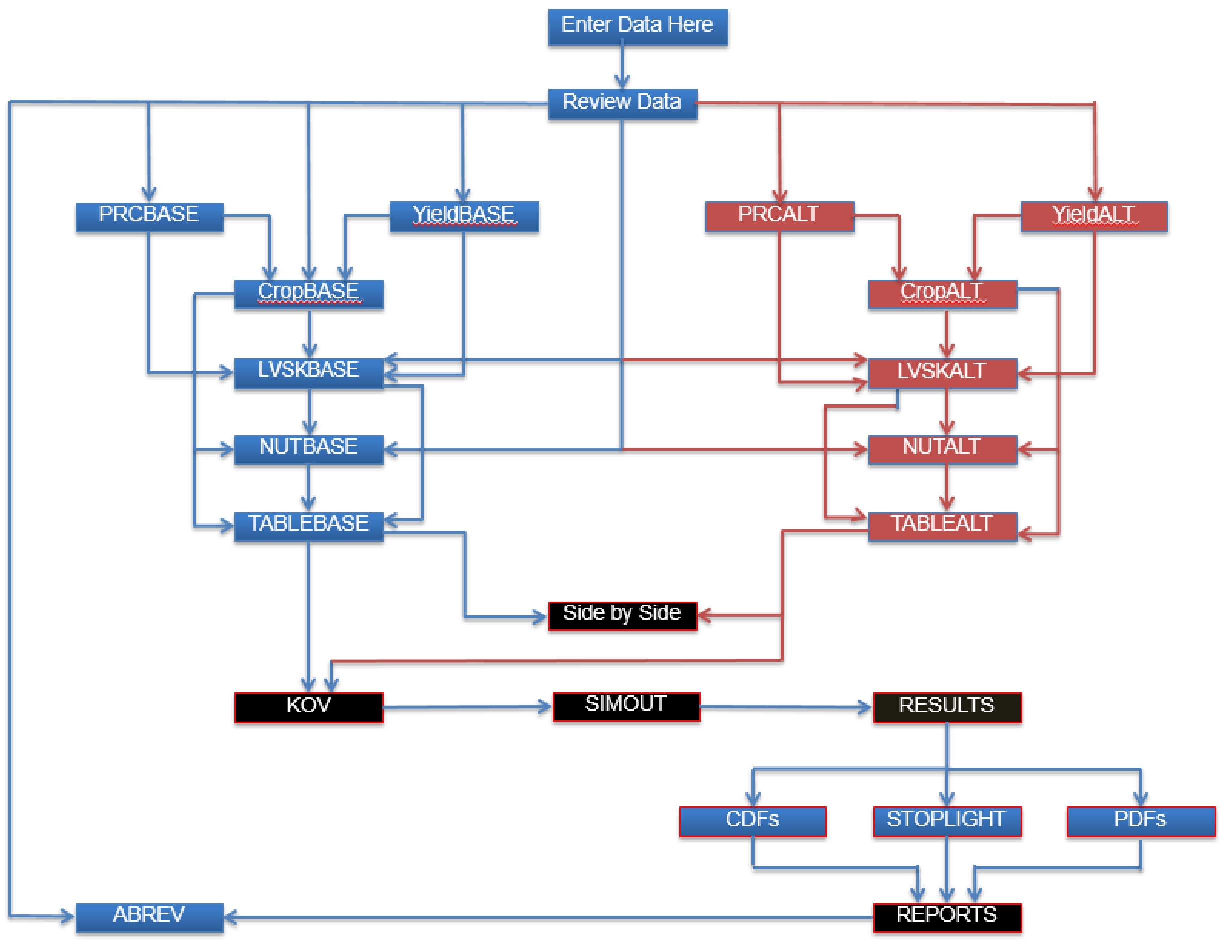
Appendix A: FARMSIM flowchart (excel worksheet organization)



***Abbreviations and meaning of different worksheets in FARMSIM**:*

PRCBASE: price worksheet in baseline scenario

CropBASE: crop worksheet in baseline scenario

LVSKBASE: livestock worksheet in baseline scenario

NUTBASE: nutrition worksheet in baseline scenario

TABLEBASE: table worksheet in baseline scenario

<u>Note</u>: same meaning of the above worksheets applies to the alternative scenarios (CropALT)

KOV: key output variable

SIMOUT: simulation output