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Application of Integrated Decision Support Systems to improve livestock systems in Ethiopia through climate-resilient approaches

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Final Report

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Contents

Executive summary

Agriculture in Sub-Saharan Africa is largely rainfed and most often affected by drought and dry spells. This is the case for Ethiopia which has experienced over years extreme weather variability that includes erratic rainfall and flooding. Climate variability or change ultimately undermines the livelihoods of smallholder farmers. Land and water management practices as well as adaptation approaches have been suggested as key interventions to build socio-economic and ecological resilience. These practices that include small-scale irrigation (SSI) technologies can also improve ecosystem services in which farmers rely on for food and fiber in times of climatic shocks.

The Feed the Future Innovation Lab for Small-scale Irrigation (ILSSI) has developed an Integrated Decision Support System (IDSS) to evaluate the integrated impacts of farming systems on production, environmental sustainability, and household income and nutrition. ILSSI has generated insights on technologies that improve production, environment and socio-economic wellbeing of households – all of which improve the resilience of people and environment that households and communities rely upon. Increases in crop and livestock productivity, using climate-resilient approaches, are believed to enhance household resilience to drought and market price shocks. IDSS as an analytical tool is used to assess the outcomes and impact of improved livestock production technologies, in the context of climate variability, on the socio-economic and resilience of households in Ethiopia. This report has two main chapters. The first chapter discusses the effect of climate variability on fodder production in Ethiopia. The second chapter discusses the economic and nutrition impacts of irrigated fodder, under different scenarios, on households in Amhara region of Ethiopia.

Chapter 1: Effect of climate on fodder production and identification of fodder production potential areas in Ethiopia

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1. Introduction

Agriculture is the most important economic sector in Ethiopia contributing more than a quarter of the country's gross domestic product (GDP) and export earnings (Yami and Sileshi 2001). The sector employs more than 80% of the population (Chauvin et al. 2012, Diao et al. 2010). Agriculture in Ethiopia is largely a rain-fed, subsistence, mixed farming, and livestock system-based that operates in a rainfall variability area where productivity is highly affected.

In Ethiopia, livestock is an integral part of the agricultural system accounting for about 40% of the economy and employing over 30% of the agricultural labor force, and serving as a source of food, cash income, and farm power for plowing and transportation (Asresie and Zemedu 2015, Declaration 1996). Raising livestock also serves as a source of insurance in times of crisis and contributes to poverty reduction (SDG 1) through building resilience, improving farming productivity, and increasing market participation (UN-SDGs 2017). Since livestock is the source of animal-origin foods, it provides as well, a wide range of micronutrients that support healthy lives and well-being for all in all age groups (SDG 3). Moreover, given that livestock accounts for a substantial share of the agricultural GDP, improving the livestock value chain through training, and technological intervention can promote inclusive and sustainable economic growth (UN-SDGs 2017). Improving livestock productivity (especially in pastoralist areas) may reduce competition for resources, and thereby promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels (UN-SDGs 2017). The development of improved livestock feed production systems can protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and rehabilitate land degradation and biodiversity loss (UN-SDGs 2017).

Since the industrial revolution, greenhouse gases emission has led to global warming. The Intergovernmental Panel on Climate Change (IPCC) reported that the atmospheric concentration of carbon dioxide increased from 280 ppm in 1750 to 412 ppm in 1999 (IPCC 2012). Climate change will have a profound effect on the availability and distribution of freshwater. The effect of climate change will be significant in developing countries where their economy is largely dependent on rainfed agriculture. This study evaluates the potential effect of climate change on fodder production in Ethiopia. In Ethiopia, various species of fodder crops are grown to feed the livestock. In this study, we focus on Napier grass (*Pennisetum purpureum*), vetch (*Vicia villosa*), and oats (Avena sativa), which are the most widely used fodder crops used for livestock feed due to their high yield and easy management (Orodho, 2006; Getu, 2015).

This project focuses on utilizing the component of the Integrated Decision Support System (IDSS) to evaluate the effect of projected climate data on fodder production in two watersheds in Ethiopia. In addition, the study identifies potential fodder production sites in Ethiopia by applying a GIS-based multi-criteria evaluation technique. Recently, the part of the IDSS was used to study the integrated impact of improved livestock technologies, especially fodder production systems on the well-being of populations in Ethiopia (Worqlul et al. 2021). In this proposed research, we intend to apply the IDSS to analyze the effect of plausible climate change on production, and environmental sustainability. Understanding climate shocks and stresses in Ethiopia will help to identify and implement appropriate adaptation and mitigation strategies. The study will help us understand the mechanisms to improve current livestock production systems through the use of climate-resilient and adapted technologies and practices.

2. Methodology

2.1. Study area

The study sites are located in two different agroecological zones in Ethiopia. The first site Robit watershed is located in the northern part of Ethiopia in the Amhara Region between 11°37’00” N, 37°26’00” E, and 11°42’00” N, 37°31’00 E. The second site Lemo watershed is located in the Southern Nations, Nationalities, and People's Region (SNNPR) between 7°20’00” N, 37°37’00” E, and 7°46’00” N, 37°53’00” E (Figure 1). The watersheds size of Robit and Lemo is approximately 15 km^2 and 482 km^2, respectively. The average watershed slope estimated from a 30 m resolution Digital Elevation Model (DEM) is 8% for Robit and 11% for Lemo watershed. The major types of livestock raised in these watersheds and the surrounding area are cattle, goats, sheep, donkeys, and mules. The main livestock outputs include meat, milk, and manure. Some of the livestock provide labor for plowing and transportation (Worqlul et al. 2021).

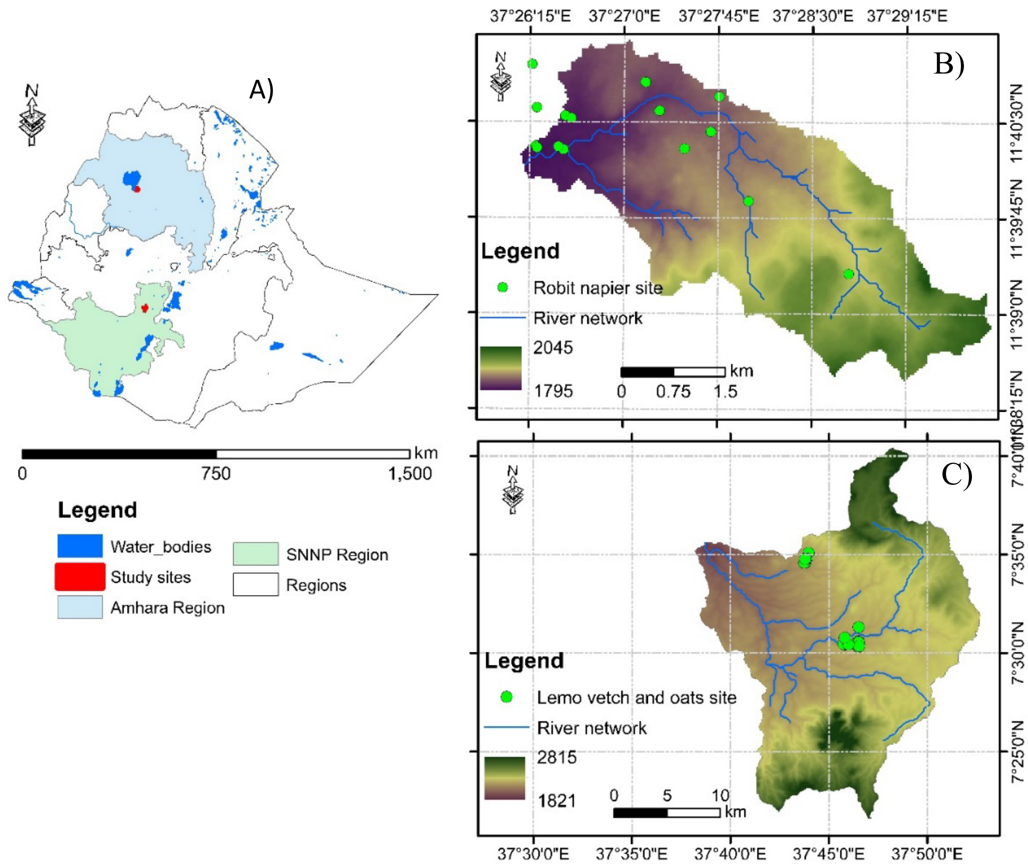


Figure 1: Location of study sites in Ethiopia with river networks and showing experimental plots. A) Map of Ethiopia with regional boundaries, B) Robit watershed showing of the location of Napier grass growing sites and, C) Lemo watershed showing the location of oats-vetch growing sites. The background image of the watersheds is a 30 m resolution DEM.

2.2. Methods

The study focuses on identifying the potential fodder production areas in Ethiopia by applying GIS-based Multi-Criteria Evaluation (MCE) techniques. This research also applies the Agriculture Policy Environment eXtender (APEX, Wang, X., Tuppad, P., & Williams, 2011) to assess the impacts of improved livestock systems, with regard to changing climate, on production and environmental sustainability. The APEX model simulates the impacts of land and water management decisions on production and the environment at the farm/field scales.

The APEX model was set up using the fodder field data in Robit and Lemo watersheds. Calibration of the model was done using APEX-CUTE (auto-Calibration and Uncertainty Estimator) to capture the observed fodder yield and height. The calibrated model was then further used to evaluate the effect of climate change on fodder production using projected future climate data. The climate change study was accomplished with the assumption that the baseline period of irrigation water is available during the projected time horizon. The future projected climate data was collected from Coordinated Regional Downscaling Experiment (CORDEX) (Christensen et al. 2014). The study considers a medium Representative Concentration Pathway (RCP4.5) for the period 2030 to 2090. The climate data collected includes rainfall, and minimum and maximum temperature. The future projected climate data was evaluated for three-time horizon windows representing 30 years' time period of 2030 -2059 (2040s), 2060 – 2089 (2070s).

2.2.1. Field data collection

Field experimental sites were established in Robit and Lemo watersheds. In Robit watershed, 15 farmers were selected to grow Napier grass using irrigation during the dry season (March to June). While in Lemo watershed, 15 farmers cultivate a mix of vetch and oats at a planting ratio of 3 vetches to 1 oat during the dry season (May to July). In both sites, the sizes of the plots vary between 50 to 140 m^2. Across the experimental plots, the following information was collected including planting dates, irrigation, and fertilizer application dates and amounts, soil moisture content, crop height, and yields. Soil samples were collected for two layers of the top 60 cm, which were analyzed to determine the soil physical and chemical properties such as texture, field capacity, available organic matter, pH, total nitrogen, available phosphorus, and electric conductivity. Detailed information on the experiment can be found Worqlul et al. (2021).

2.2.2. Identification of fodder production areas

The land that is potentially suitable for sustainable fodder production in Ethiopia was identified using a Global Information Systems (GIS)-based Multi-Criteria Evaluation technique. The analysis was done by mapping major factors affecting the suitability of the land for fodder production followed by reclassifying, assigning weights, and overlaying factors to develop a single-index fodder suitability map. The key factors were identified based on recommendations found in the literature and feedback from experts in the region (Akıncı et al. 2013, Assefa et al.

2018, Chen et al. 2010, Worqlul et al. 2017). The study considered biophysical factors such as climate (rainfall, evaporation), soil (soil texture, pH, soil depth), land use, and slope, while the socioeconomic factors included access to market and feed demand, which was represented by proximity to paved roads and livestock density, respectively. The source and spatial resolution of the data are shown in Table 1. The fodder crop types for the study were selected by the International Livestock Research Institute using on-farm trials conducted by the Innovation Lab for Small Scale Irrigation and the potential for the aforementioned three fodder crops to fit well into different agro-ecological settings in Ethiopia. These crops may improve household income and nutrition if scaled sustainably.

Table 1: Input data source and spatial resolution used for the land suitability analysis.

Data	Source	Spatial resolution (m)
Land-use	Global Land Cover Datasets (GlobeLand30)	30
Soil	Africa Soil Information Service (AfSIS), 2015	250
Soil pH	Africa Soil Information Service (AfSIS), 2015	250
Soil depth	Africa Soil Information Service (AfSIS), 2015	250
Digital Elevation Model (DE	Enhanced Shuttle Land Elevation Data from the United States Geological Survey (USGS), 2000 released in 2015	30
Road network	Digital Chart of the World (DCW), 2006	--
MODIS potential evapo (mm)	MOD16 Global Terrestrial Evapotranspiration Data Set (2000 to 2010)	1,000
Rainfall (mm/year)	Ethiopian National Meteorological Agency (ENMA) from 2000 to 2010	--
Fodder crop characteristics	FAO-EcoCrop database	--
Livestock population density	Ethiopian Central Statistical Agency (ECSA)	--

2.2.3. Biophysical modeling

The APEX model is a semi-distributed biophysical model (Gassman et al. 1998, Gassman et al. 2009). In the model, the watershed is subdivided into multiple homogenous sub-watersheds (Aubareas) based on slope, crop management, and soil information. The APEX model is driven by climate data (rainfall, relative humidity, minimum and maximum temperature, wind speed, and solar radiation), management schedule, and soil information. The model operates on a daily timestep while outputs can be reported on a daily, monthly, or annual basis. Computation in the APEX model as SubArea level, which is assumed to be homogeneous in terms of climate, slope, soil, and crop management. The model has a routing component for water, sediment, nutrient, and pesticides between the subareas.

The model was set using Robit and Lemo watersheds fodder field data and calibrated to capture the observed yield and fodder height data. Once the model is calibrated for the baseline period (1990 to 2020), the calibrated model was used to evaluate the effect of climate change on actual evapotranspiration and fodder yield during the future time horizons (2030 – 2089).

2.2.4. Projected climate data

The potential effect of climate change was evaluated using future projected climate data from CORDEX. The projected climate data has a spatial resolution of 25 km and it provides an internationally coordinated framework to improve regional climate scenarios (Giorgi and Gutowski Jr 2015). For this study, a medium Representative Concentration Pathway (RCP4.5) was used to evaluate the effect of projected climate data on fodder production on the respective sites. The future projected climate data for the period 2030 to 2089 were partitioned into three-time horizons which are 2030 -2059 (2040s) and 2060 – 2089 (2070s) and compared with the baseline period (1990 to 2020). The projected climate data of the future time horizon was used to evaluate the effect of climate change on fodder production using the APEX model.

3. Results and discussion

3.1. Identifying the land that is potentially suitable for irrigation

The GIS analysis indicated that among the factors considered for the suitability analysis, slope and soil properties (i.e., depth, pH) were the most important factors for the suitability of land for fodder production in Ethiopia. Those factors reflect the integrated effect of the role of land management and soil health on the suitability of land for fodder production. Road proximity and livestock population showed a modest influence on the land suitability for fodder production, while land use, rainfall deficit, soil texture, and temperature were the least important factors affecting the suitability of the land for fodder production. The preliminary suitability analysis showed that the suitability score ranged from 48% to 94%, 39% to 93%, and from 38% to 94% for Napier, Vetch and oats, respectively. The smallest value in the suitability score represents the least suitable land and the highest score represents the most suitable land (Figure 2). A constraint map that excludes unsuitable areas such as bodies of water and protected areas were excluded, and the most suitable land areas were identified with a user-defined threshold suitability value. The suitable land extracted for a variable threshold from 80% to 94% (with a 1% increment) from the preliminary suitability map and the respective area above the threshold was plotted (Figure 2d). For example, at an 85% threshold, 2% of the landmass was suitable for Napier production using surface irrigation, while at the 80% threshold, about 9% (22,600 km2) of the land was suitable for surface irrigation. The suitability analysis indicated that the country has the largest suitable area for Vetch (23%), Napier (20%), and oats (12%) (Figure 2a, b, and c).

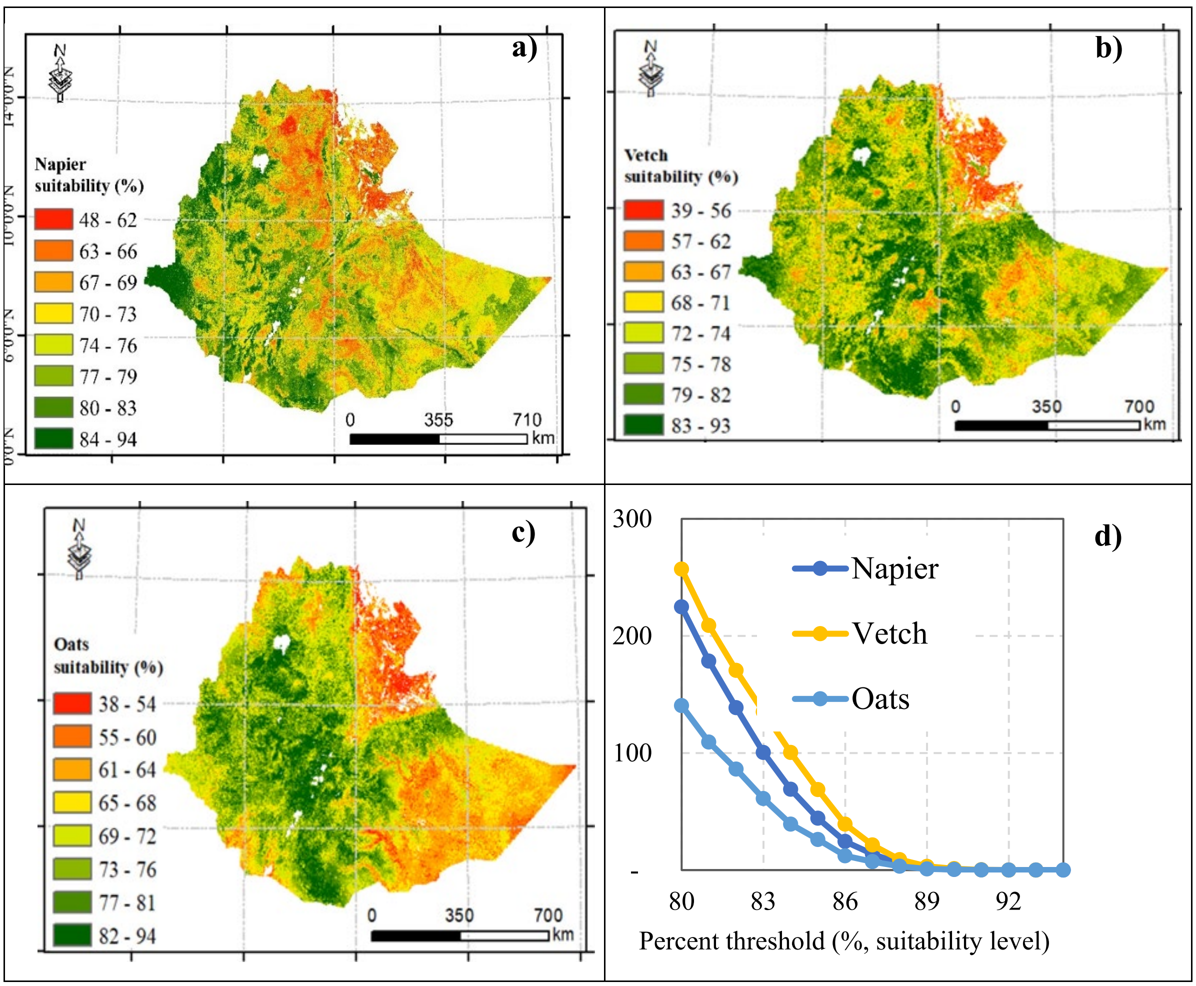


Figure 2: A preliminary suitable land for fodder production. a) Napier, b) Vetch, c) Oats and d) Fodder production suitable area (in 1000 km2) at different suitability levels.

3.2. Model calibrations and validations

The APEX model setup for Napier sites captured the observed yield very well with a correlation coefficient of 86%. Which indicated that 86% of the fodder yield variability was captured by the model and the result indicated a 0.6 t/ha of root mean square error. The simulation of the model was also evaluated with the fodder height. Where the simulated and observed Napier yield showed a correlation coefficient of 0.95. The simulation of the mixed cropping (oats and vetch) also indicated an accepted simulation capturing the observed vetch and oats yield with an average difference of 13% for oats and 6% for vetch. The model performance was also validated using the observed fodder height. The result indicated an acceptable performance with an R-square of 0.89 and 0.82 for oats and vetch, respectively.

3.3. Future climate data

3.3.1. Projected precipitation

The monthly average rainfall of the baseline period was compared with the projected climate data (the 2040s and 2070s) for Robit and Lemo (Figure 3a and b). In general, the average annual rainfall is expected to increase by 5.1% in the 2040s and by 2.3% in the 2070s from the baseline period in Robit while in Lemo, the annual rainfall is expected to decrease by 7.2% and 4.8% from the baseline period for the period of 2040s and 2080s, respectively. The projected rainfall did not show a significant change from the baseline in the majority of the dry season in Robit (January, February, March, April, November, and December). In Robit, the projected rainfall estimated a decreasing rainfall trend immensely before and after the major rainfall season in May and October, however, the projected rainfall is expected to increase during the major rainfall season for both projected time horizons (Figure 3b). The projected rainfall in Lemo indicated a decreasing trend in the dry season (January to May) while expected to increase during the major rainfall season (July, August, and September).

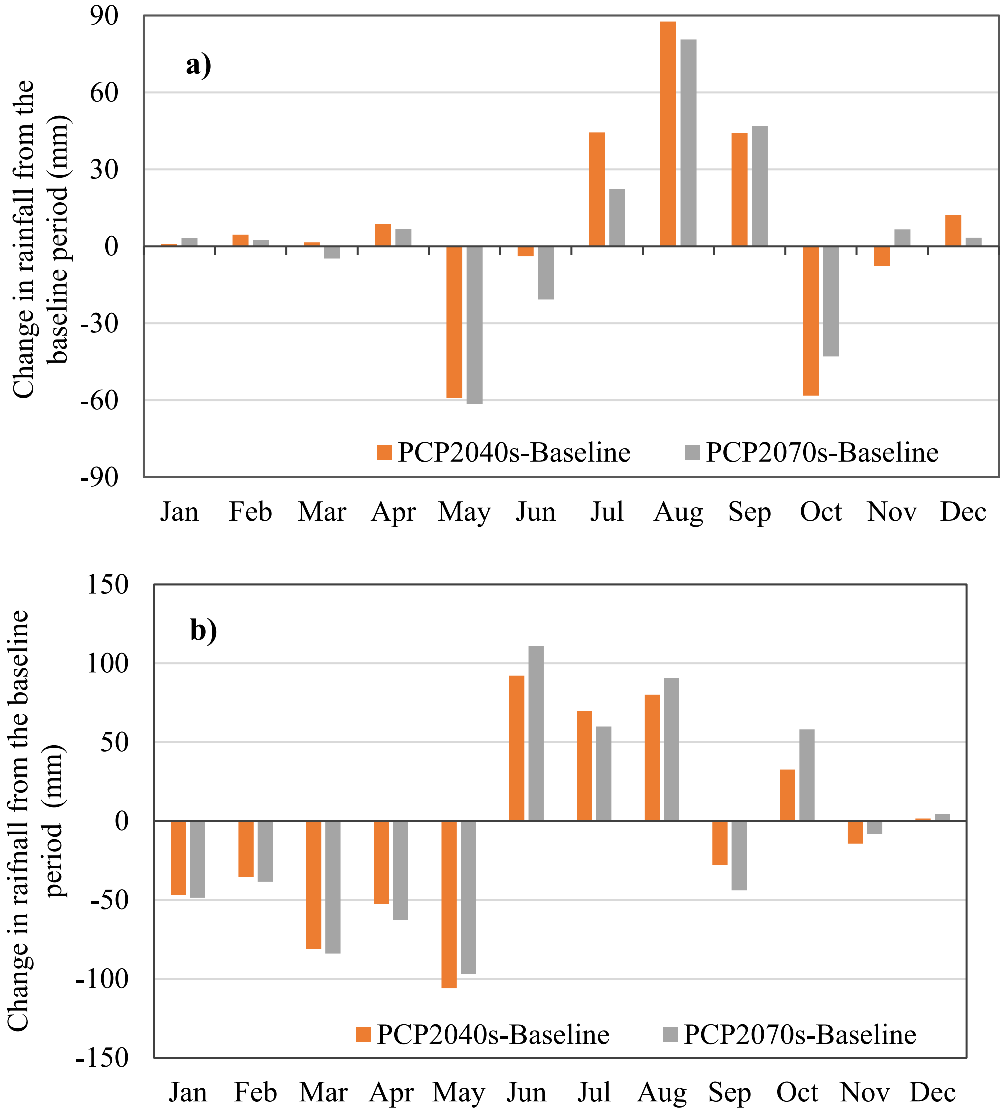
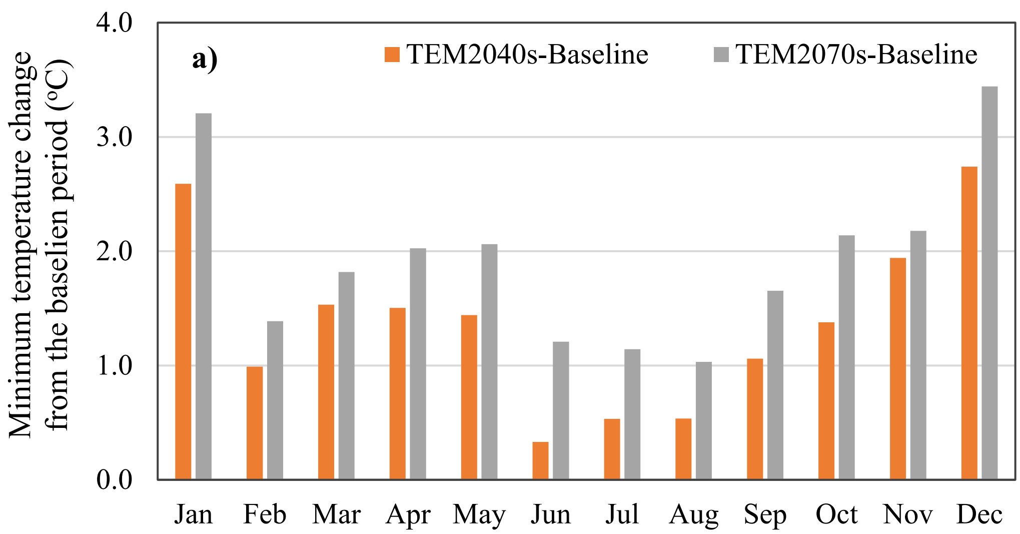


Figure 3. Average monthly rainfall difference of the projected rainfall (2040s and 2070s) from the baseline period. a) Change in rainfall for Robit and b) Change in rainfall for Lemo.

3.3.2. Projected minimum and maximum temperature

The average long-term projected temperature of both sites was compared with the respective baseline period (Figure 4a, b). For Robit, the projected minimum temperature is expected to increase by 1.38ºC and 1.94ºC from the baseline period for the 2040s and 2070s time horizons, respectively (Figure 4a). The maximum temperature of Robit watershed is expected to decrease by 0.51ºC in the 2040s but in the 2070s the maximum temperature did not show a significant difference from the baseline period (Figure 4b). In Lomo, both the minimum and the maximum temperature are expected to increase for both time horizons (Figure 5a and b). In the 2040s, the minimum and the maximum temperature are expected to increase by 3.09ºC and 1.47ºC, respectively (Figure 5a). In the 2070s, the minimum and maximum temperature in Lemo is expected to increase by 3.58ºC and 2.25ºC, respectively (Figure 5b). The increasing minimum and maximum temperature in Lemo during the dry season will significantly affect the irrigated fodder water requirement.



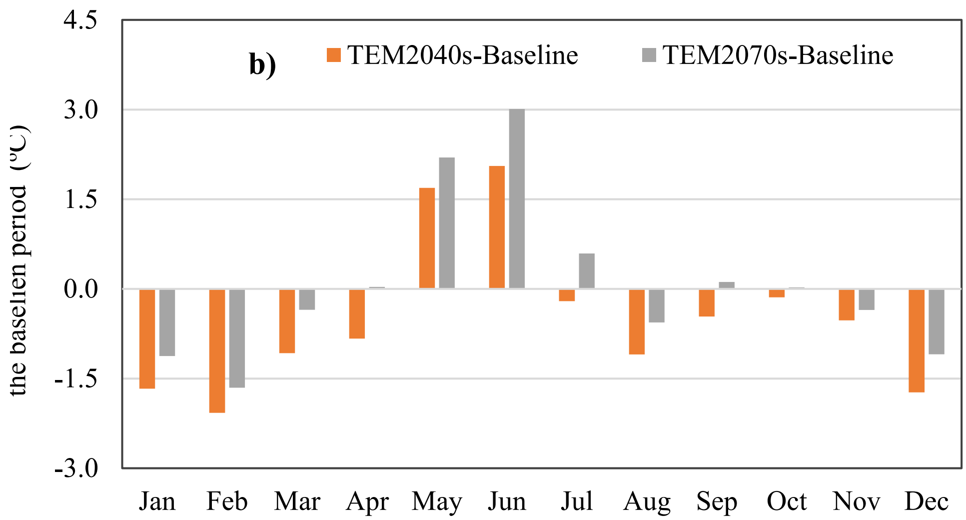
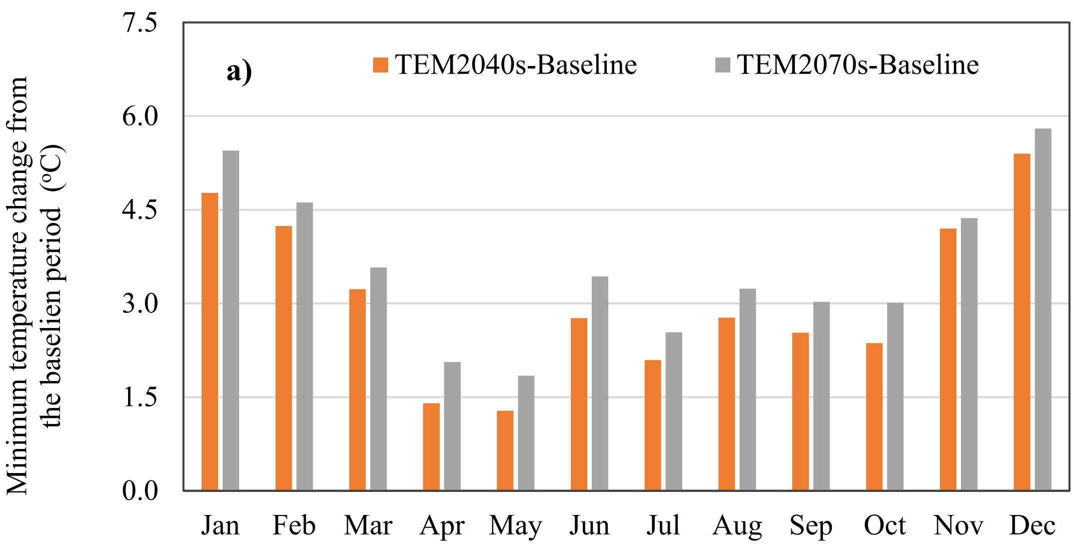


Figure 4. Projected Robit long-term average minimum and maximum temperature change from the baseline period. a) Longterm minimum temperature change from the baseline

period for the 2040s and 2070s. b) Longterm maximum temperature change from the baseline period for the 2040s and 2070s.

During the fodder growing period, in Robit, rainfall is expected to decrease by 14.8% in the 2040s and 22.6% in 2070s. During the same period, the minimum temperature is expected to increase by 8.2% in the 2040s and 12.1% in 2070s. The maximum temperature is also expected to increase by 1.7% and 4.5% in the 2040s and 2070s. In Lemo, climate change will have a moderate effect on irrigated vetch and oats compared to Robit site. In Lemo, rainfall is expected to increase by 0.6% and 1.8% while minimum temperature is expected to increase by 13.5% and 17.7% in the 2040s and 2070s, respectively. The maximum temperature is expected to increase by 5.9% and 8.9% in the 2040s and 2070s, respectively.



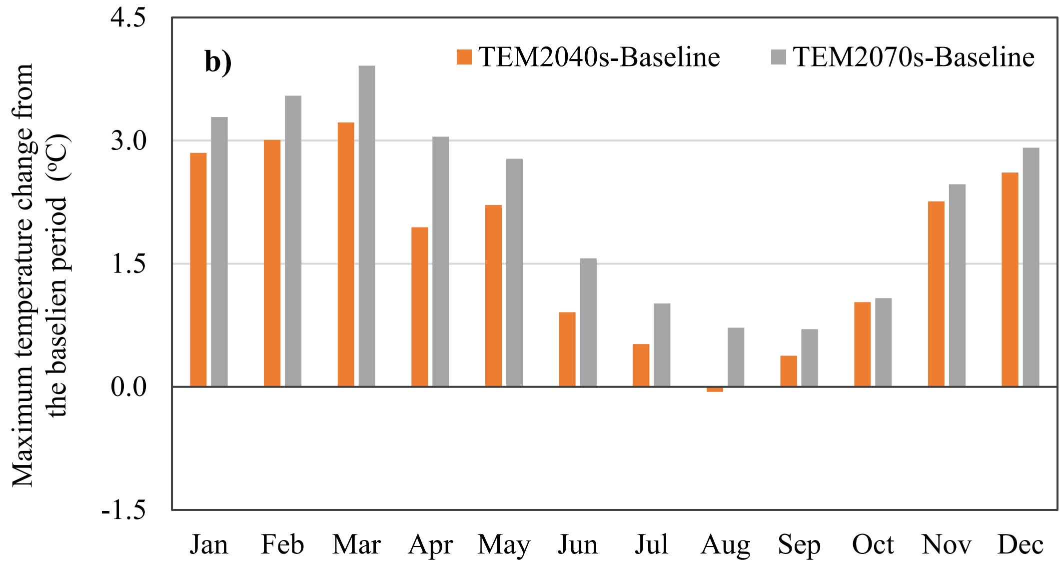
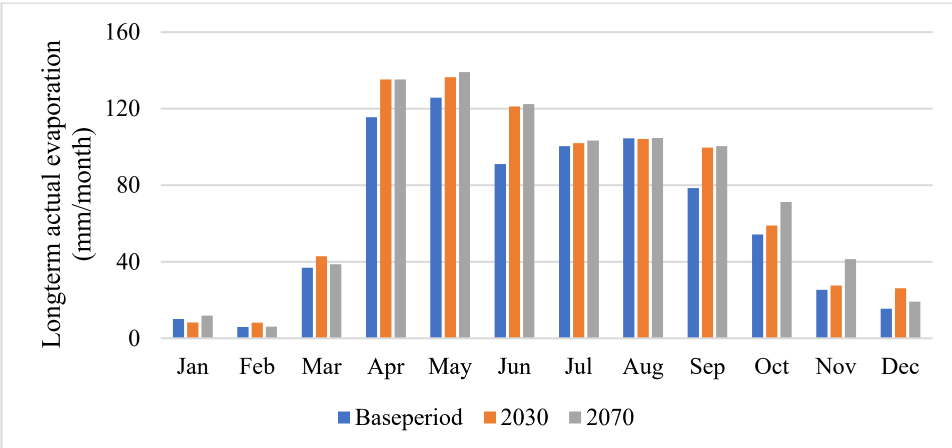


Figure 5. Projected Lemo long-term average minimum and maximum temperature change from the baseline period. a) Longterm minimum temperature change from the baseline period for the 2040s and 2070s. b) Longterm maximum temperature change from the baseline period for the 2040s and 2070s.

3.3.3. Effect of climate change on irrigated fodder production

The effect of climate change on fodder production was evaluated using the calibrated APEX model. The calibrated APEX model for the baseline period was rerun with the projected climate data for the 2040s and 2070s. Then the potential and actual evaporation and the fodder yield were compared. Figure 6a and 6b show the comparison of the actual evaporation of the 2040s and 2070s of Robit and Lemo sites, respectively. Due to climate change, in Robit, the actual evapotranspiration is expected to increase by 14% and 17% in the 2040s and 2070s, respectively. While in Lemo, the simulation indicated that the actual evaporation will increase by 7.5% in the 2040s and 10.3% in the 2070s. The actual evaporation was also compared during the fodder irrigation period from March to June for Napier grass, the result indicated the actual evaporation will increase by 18.0% and 17.9% in the 2040s and 2070s, respectively. In Lemo, the actual evaporation during the irrigation period will increase by 1.9% and 3.8%, respectively. The climate change analysis indicated that the extent of climate change effect on irrigated fodder will vary from place to place. However, the analysis indicated that climate change will increase the crop water requirement of irrigated fodder indicating a need for effective water management for sustainable fodder production.



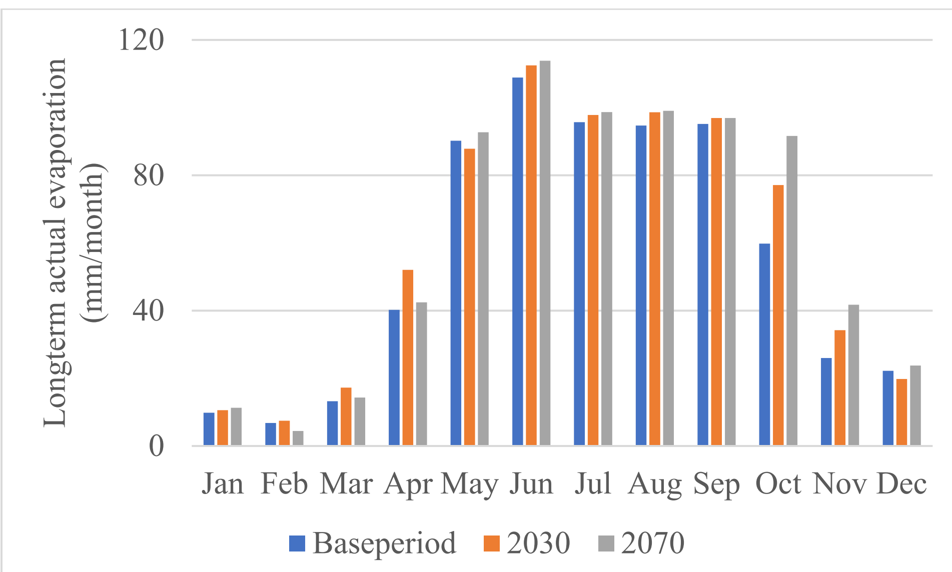


Figure 6. Comparison of simulated long-term average monthly actual evaporation during the baseline period and for the projected time horizons in Robit and Lemo watersheds. a) actual evaporation in Robit and b) actual evaporation in Lemo.

The simulated yield during the projected time horizon indicated a significant difference from the baseline period for the studied fodder crops. Due to climate change, Napier yield is expected to increase by 16.2% and 18.2% from the baseline period for the 2040s, and 2070s, respectively.

Climate change will have also a positive effect on vetch and oats yield in Lemo. Vetch yield is expected to increase by 24.5% and 14.3% in the 2040s and 2070s, respectively. Oats yield is expected to increase by 13.1% and 17.9% in the 2040s and 2070s, respectively. This study assumes that the amount of water applied during the baseline period is available during the projected time horizons.

The simulation also indicated an increase in the nitrogen stress days in the future time horizons for Napier, from 9 stress days in the baseline period to 23 days in the 2040s and 26 days in the 2070s. Indicating that the addition of nitrogen to the soil will further increase Napier production. In the model, the number of nitrogen stress days were estimated by comparing the available amount of soil nitrogen in the root zone and the daily nitrogen demand for optimal growth. For example, the number of nitrogen stress days is estimated at 0.2 days if the root zone readily available nitrogen meets only 80% of the optimal nitrogen requirement for the respective fodder crop.While for oats there was not much difference in the number of nitrogen stress days.

4. Conclusions

This study examined the effect of potential climate change on fodder production in Ethiopia by integrating field data and a biophysical model. Fodder field experimental plots were established in the Amhara and Southern Nations, Nationalities, and People's Regions, and the Agriculture Policy Environment eXtender (APEX) model was used for the effect of potential evaporation on fodder production. In addition, the potential fodder production sites at the national level were identified using a Global Information Systems (GIS)-based Multi-Criteria Evaluation technique. The result of the climate change analysis indicated that the average annual rainfall is expected to increase by 5.1% in the 2040s and by 2.3% in the 2080s from the baseline period (1990 to 2020) in Robit while the annual rainfall is expected to decrease by 7.2% and 4.8% from the baseline period for the period of 2040s and 2080s, respectively in Lemo watershed. The projected minimum temperature is expected to increase by 1.38ºC and 1.94ºC from the baseline period for the 2040s and 2070s time horizons, respectively. Robit maximum temperature is expected to increase by 0.51ºC in the 2040s but in the 2070s there is no significant change compared to the baseline period. In Lomo, both the minimum and the maximum temperature indicated an increasing trend for both time horizons. The increasing temperature during the future time horizon will have a significant effect on the potential evaporation. Due to climate change, in Robit, the actual evapotranspiration is expected to increase by 14% and 17% in the 2040s and 2070s, respectively. While in Lemo, the simulation indicated that the actual evaporation is expected to increase by 7.5% in the 2040s and 10.3% in the 2070s. The APEX model also indicated that, due to climate change, Napier yield is expected to increase by 16.2% and 18.2% from the baseline period for the 2040s, and 2070s, respectively. Climate change will have also a positive effect on vetch and oats yield in Lemo. Vetch yield is expected to increase by 24.5% and 14.3% in the 2040s and 2070s, respectively. Oats yield is expected to increase by 13.1% and 17.9% in the 2040s and 2070s, respectively.

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Chapter 2: Simulation of Economic and Nutrition impacts of irrigated fodder at the household level in Amhara region of Ethiopia

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1. Background

Agriculture in Ethiopia is largely a rain-fed, subsistence, mixed farming, and livestock system-based that is subject to rainfall variability that can affect productivity and food security. At the household level, beside the critical economic and social roles that livestock plays in the livelihoods of smallholder farm households and pastoralists, they help people cope with shocks and accumulate wealth as a store of value where regular financial institutions are not present. In smallholder mixed farming systems, livestock products provide nutritious food, additional emergency and cash income as well as input for agricultural farming.

According to the United Nations Sustainable Development Goals (UN-SDGs), raising livestock also serves as a source of insurance in times of crisis and contributes to poverty reduction (SDG 1) through building resilience, improving farming productivity, and increasing market participation (UN-SDGs, 2017). Since livestock is the source of animal origin foods, it provides as well, a wide range of micronutrients that support healthy lives and well-being for all at all age groups (SDG 3). Moreover, given that livestock accounts for a substantial share of the agricultural GDP, improving the livestock value chain through training, and technological intervention can promote inclusive and sustainable economic growth (UN-SDGs, 2017). Improving livestock productivity (especially in pastoralist areas) may reduce competition for resources, and thereby promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels (UN-SDGs, 2017).

Despite its importance, several constraints related to livestock production and productivity such as the lack of feeds, remain a major barrier to the development of the livestock sector in Ethiopia (Bezabih et al., 2016). Improving animal feed resources can have impacts on both household income and nutrition through the production, consumption, and sale of live animals and animal products. Also, climate variability or change is undermining the livelihoods of smallholder farmers, requiring better land and water management practices for adaptation and resilience. In particular, during drought periods, there is a potential to enhance fodder production with irrigation, for animal feed, which increases resilience and avoid massive losses of livestock due to lack of feed and water. In 2015 and 2016, an El Niño-induced drought destroyed the pastures of Ethiopia's lowlands leading to enormous feed and water deficits across the livestock-dependent regions in Ethiopia and causing the loss of several thousands of animals (FAO, 2016).

In this study, small scale irrigation (SSI) technologies along with fertilizer will be used to grow and improve yields of fodder (Oats & vetch; Napier) with the purpose to feed animals and generate income. Supplementing animal feeding with fodder is expected to increase milk production and animal weight which in turn will improve family nutrition and generate income. Small scale irrigation can enable dry season cultivation of crops (vegetables, fodder, etc.), while also providing supplementary irrigation for the rainfed crops during periods of dry spells and drought. Given the importance of livestock in emergency and cash situations, producing fodder for animal feed in stress periods like drought through irrigation is paramount to build households resilience in time of climate variability.

This study utilizes the Integrated Decision Support Systems (IDSS) to evaluate the integrated impacts of smallholder farming systems on production, environmental sustainability, household income, and nutrition in Ethiopia. The overall objective of the study is to apply the IDSS as an analytical tool to assess the outcomes and impact of improved livestock production technologies, in the context of climate variability, on the socio-economic and resilience of households in Ethiopia. The study will help understand the mechanisms to improve current livestock production systems through the use of climate-resilient and adapted technologies and practices.

Understanding climate shocks and stresses in Ethiopia will help identify and implement appropriate adaptation and mitigation strategies. For this reason, IDSS will use remote sensing data to monitor drought and characterize climate severity and subsequently identify strategies that help respond and adapt to the challenges of climatic shocks and stresses to livestock systems, especially on the fodder production side. Increases in crop and livestock productivity in adverse climate conditions for livestock production can enhance household resilience to drought and market price shocks and play a pivotal role in maintaining both the consumption levels of animal source products and livestock assets.

2. Study site selection and data

2.1. Study site selection

The Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI) has a strong presence in Ethiopia with multiple research sites across different agro-ecological zones and strong collaborative relationships with local universities and federal and regional research offices. The Innovation Lab project, operating under Texas A&M AgriLife Research, has been collecting field data from multiple sites in Ethiopia since its beginning in 2013, that include Robit (Amhara region) and Lemo (SNNP region). The field data collected provides information related to field experiments and feed the bio-physical and socio-economic models to evaluate the impacts of improved livestock systems on production, environmental, economic, and nutrition outcomes. The field data are also used to identify gaps and constraints of fodder production and build farmer's resilience to changing climate. Due to data availability, the Robit kebele, located in the Amhara region near the regional capital Bahir Dar was selected as study site (Figure 2.1).

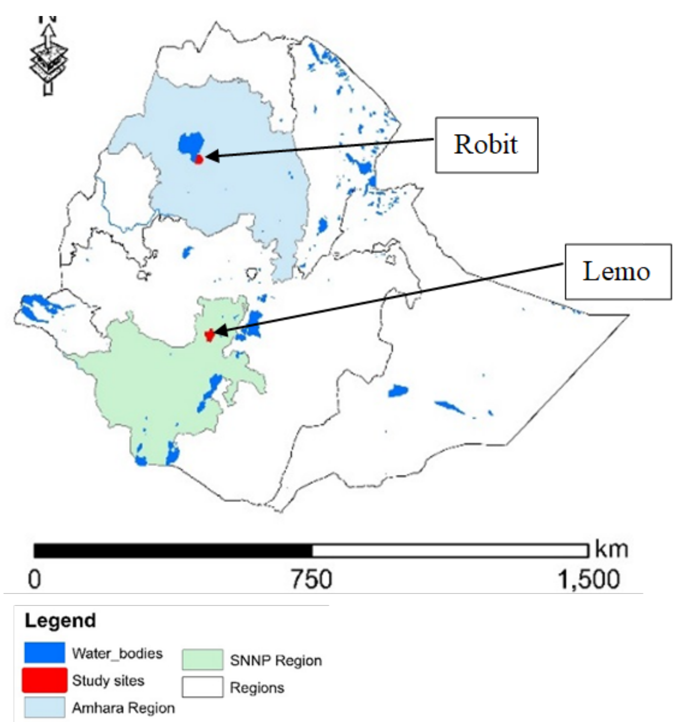

Figure 2.1: **Location of experimental sites of Robit and Lemo watersheds, Ethiopia**

Robit kebele (village) is located in Bahir Dar Zuria woreda, West Gojam zone in Amhara region of Ethiopia. The Robit village area has an average elevation of 1848 masl (meters above sea level). A mixed crop and livestock production is the predominant farming system in the area where the main crops grown include maize, finger millet, teff, rice, and chickpeas. Crops are grown using both rain and irrigation water. Two major cropping seasons are identified in Ethiopia: *Kiremt* and *Bega. Kiremt* is the main rainy season (June-September) during which major field crops (mainly grains) are grown and harvested in *Meher* season. Irrigated crops such as tomatoes, grass peas, chickpeas, cabbage and onions are grown during the *Bega* season (dry from October to January). Most of the households keep cattle, small ruminants, poultry and bees (apiculture). Cattle are basically raised to meet draught power requirements while milk, meat, manure, dung cake, breeding replacement stock are income sources. The majority of the milk produced is retained for home consumption. However, some milk is processed into butter for sale and family consumption.

2.2.Household surveys and field data collection

The introduction of small-scale irrigation (SSI) technologies by the Feed the Future Innovation Laboratory for Small-Scale Irrigation (ILSSI) project led to field trials with local farmers beginning in 2015 in Ethiopia. Biophysical and socio-economic data were collected since 2015 on different irrigated crops that include onions, cabbage, carrots for human nutrition and on napier grass, oats and vetch for animal nutrition. The use of SSI technologies to grow forage and irrigated fodder can help increase the feed availability and also help livestock keepers and pastoralists with feeds to smooth out difficult times such as drought. 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 were irrigated and 4000 individual wells were recorded in the kebele (Assefa, 2015).

The socio-economic farm data sets developed during the field trials and implementation of the ILSSI project phase I, from 2013 to 2018 are used to define the alternative and baseline scenarios and evaluate the economic and nutrition benefits of adopting fodder production systems in Robit. An endline household survey was conducted between 2017 and 2018 by the International Food

Policy Research Institute (IFPRI)[1]. The survey information was particularly used in updating the farm simulation model baseline information.

The baseline scenario considers "no" to "minimal" irrigation based on the information from the household surveys, while the alternative scenarios consider expansion of irrigated area and optimal irrigation of vegetables and fodder during the dry season using different water lifting technologies. Solar pump was considered in this study as an irrigation tool for the future to combat climate change. Information on solar pump system (cost, flow rate) was mainly drawn from data collected in Lemo woreda ILSSI site.

Biophysical input data for both the baseline and alternative scenarios were mainly drawn from data collected in Robit between 2016 and 2017 by IWMI during the ILSSI project field interventions with local farmers on small-scale irrigation technologies. About 15 farmers participated in the field trials on improved water lifting technologies that comprised the Rope & washer pump and pulley/bucket/tank system to grow vegetables and fodder in dry season[2]. Livestock input data for the alternative scenarios were collected by ILRI during field studies on livestock nutrition and productivity.

The primary data (household surveys) were supplemented by secondary data that include expert opinion, research articles, and reports from government and non-government agencies. The information from the survey and other sources were summarized according to the FARMSIM model input datasheet which requires information on crops, livestock, assets, liabilities and fixed and variable production costs, yields, output prices, and use of crops and livestock products for human consumption and livestock feed for a representative farm.

Information on native and crossbred cows was collected from field trials and farmers in Robit kebele (Amhara). Native cows were considered in this study to take into account their potential resilience in face of future harsh climatic variability and some level of uncertainty on the performance of crossbred cows under the same conditions in the long-term. A native cow can

[1] IFPRI discussion paper: http://www.ifpri.org/publication/irrigation-and-womens-diet-ethiopia-longitudinal-study
[2] Feed the Future- ILSSI-Report: Experimental and research design – Ethiopia, https://ilssi.tamu.edu/files/2019/12/19012015_ilssi_ethiopia-research-design-2.pdf

produce about 2 liters per day with supplemental forage feeding or about 600 liters assuming 300 lactating days in a year (Blummel et al., 2018). Following are the four scenarios under study in Robit and comprise a baseline and three alternative scenarios (Alt.1.; Alt.2. and Alt.3).

- Baseline: no to minimal irrigation + no supplemental fodder feeding + local or native cows
- Alt.1-Solar_N: Solar system used in optimally irrigated systems + Supplemental fodder feeding to native cows + No climate change impacts
- Alt.2-Solar_N_CC: Solar pump used in optimally irrigated systems + Supplemental fodder feeding to native cows + Climate change impacts
- Alt.3-Solar_N_P: Solar pump used in optimally irrigated systems + Supplemental fodder feeding to native cows + No climate change impacts + Food purchase

Eight crops that include three grains (maize, teff and wheat), two vegetables (cabbage and tomatoes), one legume (chickpeas) and two fodder crops (napier and oats & vetch) were analyzed at the farm household for all the above scenarios. In all three alternative scenarios, the chickpeas and grain cropping areas, input cost and yield were kept constant as in the baseline scenario; only the crops under irrigation (tomatoes, napier and oats & vetch) had different input costs, yields, and cropping areas associated with the different SSI technologies compared to the baseline scenario (See Appendix 2.A).

2.3.Data preparation and experimental sites

Although this study focuses on Robit, field experimental sites were established in Robit and Lemo watersheds located respectively in Amhara and SNNP regions of Ethiopia. In Robit watershed, 15 farmers were selected to grow Napier grass using irrigation during the dry season (March to June). In Lemo watershed, 15 farmers cultivate a mix of vetch and oats at a planting ratio of 3 vetches to 1 oat during the dry season (May to July). In both sites, the sizes of the plots vary between 50 to 140 m^2. Across the experimental plots, the following information was collected including planting dates, irrigation, and fertilizer application dates and amounts, soil moisture content, crop height, and yields. Soil samples were collected for two layers of the top 60 cm, which were analyzed to determine the soil physical and chemical properties such as texture, field capacity, available organic matter, pH, total nitrogen, available phosphorus, and electric conductivity. Detailed information on the experiment can be found Worqlul et al. (2021).

3. Methods and approaches

This research applies the Integrated Decision Support System (IDSS, Clarke Neville et al., 2017; Worqlul Abeyou et al., 2017) to assess the impacts of improved livestock systems, with regard to changing climate, on production, environment, income, and nutrition at the household and village levels in Ethiopia. The IDSS includes the Soil and Water Assessment Tool (SWAT, Arnold et al., 1998), Agriculture Policy Environment eXtender (APEX, Wang, X., Tuppad, P., & Williams, 2011), and Farm Simulation model (FARMSIM, Bizimana and Richardson, 2019). The APEX and SWAT models simulate the impacts of land and water management decisions on production and the environment at the farm/field, and on watershed/national scales, respectively. The FARMSIM model simulates the impacts of agricultural technologies on household income and nutrition at the village and farm levels. The IDSS framework, used to assess the impacts of small scale irrigation on agricultural production, environmental sustainability, and household income and nutrition, was evaluated in watersheds in Ethiopia (Clarke et al., 2017) and Ghana (Worqlul et al., 2018) and showed promising results to support sustainable scaling of small scale irrigation in sub-Saharan Africa.

During the reporting period, the IDSS tools were calibrated using baseline information, and parameters have been transferred among the models (Figure 2.2). The SWAT model was used to divide a watershed into multiple sub-watersheds and further into multiple hydrologic response units (HRUs). The HRUs are assumed to have homogeneous land use, soil, and slope combinations where soil water content, nutrient cycles, surface runoff, and sediment yield are simulated. While in the APEX model, a sub-watershed has a single HRU, which is also referred as subarea. APEX simulates detailed field conditions including crop management and growth, nutrient and pesticide fate, hydrology, soil temperature, and erosion-sedimentation as well as impacts of different farming systems.

As part of the IDSS integration, large-scale hydrologic parameters were transferred from the SWAT model to the APEX model, and crop related information was transferred from APEX to the SWAT model. SWAT and APEX share similar data and underlying biophysical equations to simulate biophysical processes. The APEX and SWAT models provided, respectively, a long-term crop yield and potential land to scale fodder production in the Robit watershed to the FARMSIM model. APEX simulates crop and fodder yields over 32 years period for the baseline and alternative farming systems using local weather data, and soil conditions. FARMSIM simulated the current crop and livestock system as well as an alternative farming system. In this study, FARMSIM simulated the impacts of improved livestock production systems, based on forage production, animal feeding and performance on profit and nutrition. Inputs to the FARMSIM model includes costs, yields, prices, consumption, expenditures, assets and liability have been entered into the model. Risk for crop yields, livestock production (birth rates, death rates, weight gain, and milk production), and market prices are explicitly included in the model to present the results in terms of probabilities of the key output variables (KOVs). The KOVs comprise annual net cash income, annual ending cash reserves, net present value, benefit-cost ratio (BCR), internal rate of return (IRR), and daily family nutrient consumption of protein, calories, fat, calcium, iron, vitamin A, zinc, vitamin B9 (folate) and Vitamins B12 for an adult equivalent.

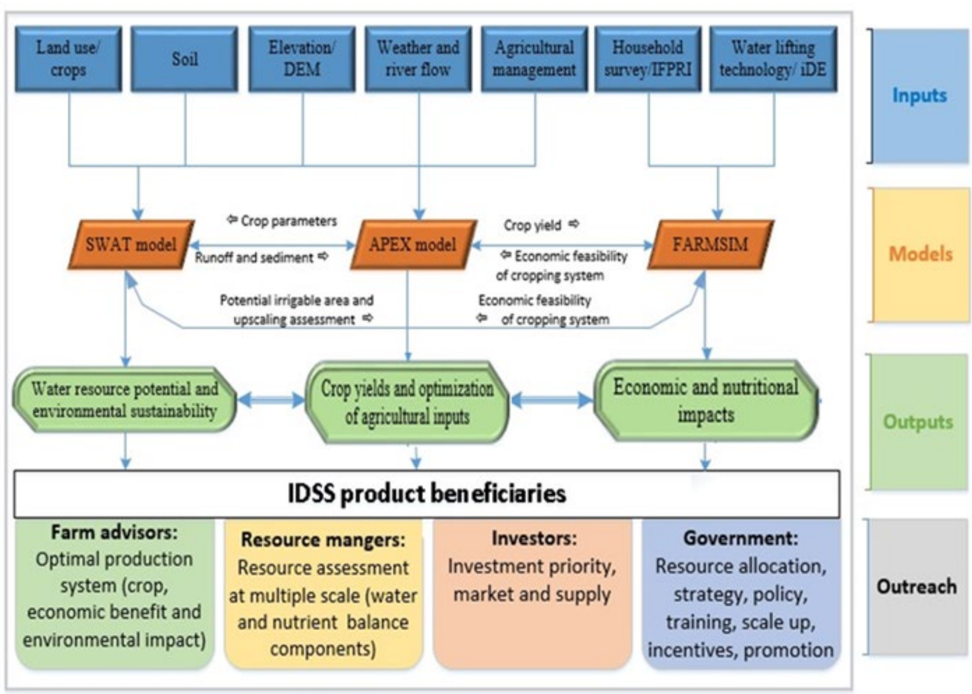

Figure 2.2. Integrated Decision Support System (IDSS) framework

The impact of climate variability on fodder production is studied using the IDSS tool to develop an agriculture system that ensures food security. The future climate data are obtained from the Coordinated Regional Downscaling Experiment (CORDEX) (Christensen et al. 2014). We captured the impacts of climate change or variability through fodder yields that were input into the FRMSIM model and simulated along other variables. In this study, we consider only napier grass and vetch & oats for Robit study site based on the information from household survey. See Chapter 1, section 3.3.3 of this report for more details on climate variability impacts.

4. Assumptions

First, to show the full potential of adopting new technologies, the alternative crop farming technologies are assumed to be fully adopted based on survey information and as demonstrated in the field trials by the intervention farmers. However, a lower and progressive adoption rate is considered for the livestock technologies in the course of the five-year forecasting period based on household survey information. For example, for livestock production technologies related to feeding animals with fodder and napier grass supplement, we assumed a 60 percent adoption rate which is two times the original 30 percent adoption rate reported in household data survey. No scientific basis guided this choice apart from the assumption of a scenario where the current adoption rate is doubled. The concern for farmers to acquire irrigation tools such as solar pumps due to the high capital cost was partially addressed by including in the model an option for loans to purchase the irrigation pumps through microfinance institutions.

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 critical. Access to markets by farmers depend in part on the existence of road and market infrastructure in the Bahir Dar Zuria district where survey indicates on average 1.4 km (0.9 miles) distance to market. With regard to market existence and operations for instance, a market research report shows that milk was sold at Bahir Dar surrounding markets with a higher demand than the supply (Wondatir et al 2015)[3]. The report indicates as well that supplemental feeds were purchased by farmers at both local and Bahir Dar markets. To maintain quality, vegetables are often sold at the farm gate,

[3] See the ILSSI report at: http://ilssi.tamu.edu/media/1372/ilssi-robit-bata-feast-report-updated-final-2.pdf

roadside and local markets in Bahir Dar. A 2017 household survey in Robit conducted by IWMI indicates as well that about 70% of the vegetables produced (mainly garlic and tomatoes) were sold by farmers at the market.

Third, an alternative scenario based on the impacts of climate change on fodder production is included in the study. The biophysical model APEX was used to evaluate the effects of climate change on fodder production using projected future climate data. The future projected climate data was evaluated for 2040s and 2070s. In this study, we considered and included in the simulation the 2040s projections results and their impacts on fodder production yields. The use of irrigation seems to mitigate the effects of climate change and simulation results show an increase of about 16 and 24% (compared to the baseline) respectively in napier and vetch yields. Note that vetch yields increase three-folds while napier yields doubled for alternative scenarios without climate change impacts and optimal irrigation and fertilizer input.

Fourth, based on preliminary simulation runs on average profitability, we estimated that households under the baseline scenarios are unable to allocate more resources than they originally planned for purchase due to cash shortage. However, each household under the alternative scenarios without climate change impacts, will be able to allocate close to 66% of their net profit to purchase supplemental foodstuffs that comprise staples and animal source foods. Households under climate change impact alternative scenario are able to make food stuff purchase originally planned but are unable to expand the purchase to animal source foods due to lower profits. In this analysis, farm families consume food grown on the farm and/or purchased at the market for their nutrition. A preliminary analysis of food items consumed by an average household in Robit indicates a predominance of a cereal-based diet with substantial shortage of animal-source food consumption. For this reason, an alternative scenario for increased purchase was analyzed where the majority of 66% of the profit portion allocated to food purchase went into milk, eggs and beef to improve nutrition. Note as well that there was a substantial increase in on-farm beef consumption fraction (10%) under increased purchase alternative compared to all other scenarios which have a small consumption fraction close to zero (0.004).

5. Results and Discussion

5.1. *Economic impacts*

The simulation results for net present value (NPV), which assesses the long-term feasibility of an investment, show a positive NPV value for all the scenarios in Robit kebele for the five-year forecasting period (Table 2.1). Although we do not see a very significant difference among scenarios, the NPV value under solar pumps, no increased purchase and no climate change scenarios (Alt. 1) show higher NPV values compared to the baseline, climate change and increased purchase scenarios (Baseline, Alt.2 and Alt.3).

The annual net cash farm income (NCFI) which represents the economic net profit at the household level shows that the average profit for five years under alternative scenarios one and three (Alt. 1 and Alt.3) is almost five times higher than that of the baseline scenario, with a percentage change in profit from the baseline to the alternative scenarios standing at 398%, 48% and 392% increase respectively (Table 2.1). A cumulative distribution function (CDF) of the net profit, shows that Alt.1 and Alt.3 under no climate change impacts have zero probability of having a loss while the baseline and Alt. 2 under climate change scenario have between 5 and 7% probability of falling below zero (Figure 2.3).

Table 2.1. Economic impacts of livestock technologies in Robit kebele

	Baseline	Alt.1-Solar_N	Alt.2-Solar_N_CC	Alt.3-Solar_N_P
Net present value (5yrs)	78,559	83,059	60,264	68,017
Tot avg. net profit	1,900	9,455	2,804	9,346
% Change profit: Alt./Baseline		**398%**	**48%**	**392%**
Benefit-Cost Ratio: Alt/Base		1.1	0.2	1.1
IRR		0.14	-0.34	0.14
Prob BCR> 1 (%)		74	0	70
Prob IRR> 0.1 (%)		73.5	0	69.9
Avg. Livestock net profit	2,637	3,365	3,365	3,256

Note: Exchange rate (2021): 1 USD = 39 Birr

The probability of loss for the baseline and climate change scenarios is mainly driven by the inclusion of the family labor costs into the total cost of production and the impacts of climate change on fodder yields. However, those costs are offset by higher profits in the other alternative scenarios (Alt.1 and Alt.3) that are not impacted by climate change. The net profit for Alt.1 and Alt.3 clearly shows higher profit compared to other scenarios as their CDF curve stands farther to the right of all other scenarios, mainly due to increase in fodder and vegetables sales.

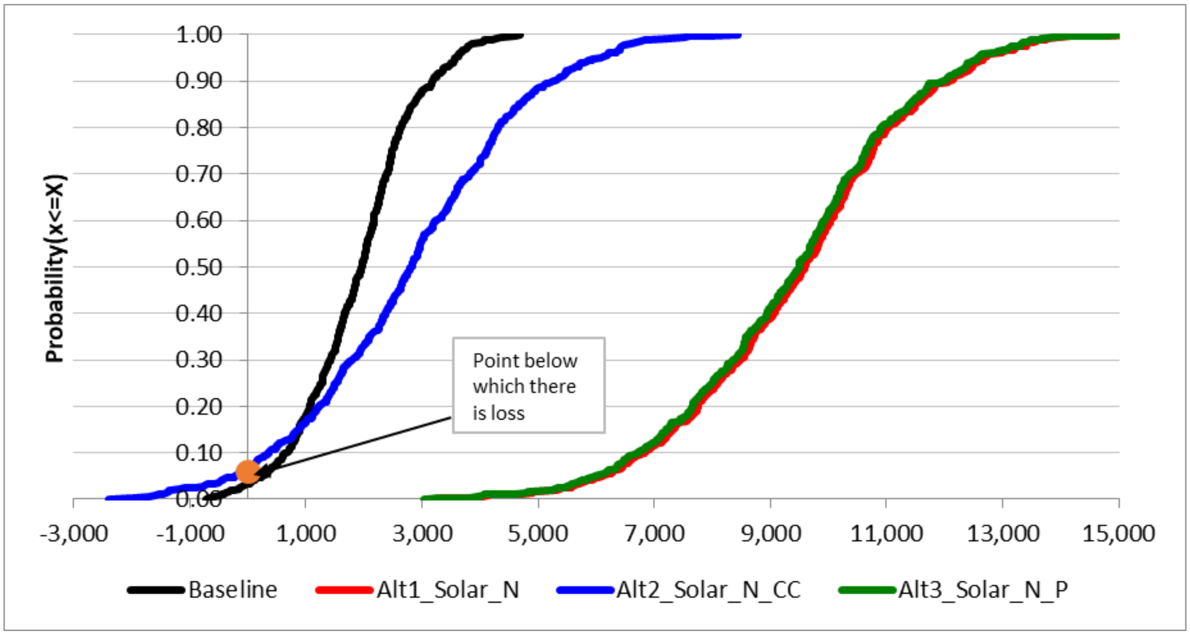

Figure 2.3. Cumulative distribution of net cash income per family in Robit kebele

To assess whether the benefits are worth the investment costs, a cost benefit analysis (CBA) is conducted using two NPV-related metrics illustrated by the benefit cost ratio (BCR) and the internal rate of return (IRR). The two metrics inform on the profitability and return on investment of new enterprise, in this case, the investment in small-scale irrigation technologies (SSI), fertilizers and fodder feeding under alternative scenarios compared to the baseline. The simulation results indicate on average that the BCR values are equal to 1.1 for alternative scenarios under solar pumps and no climate change impacts (Alt. 1 and Alt. 3) and their IRR values equal to 0.14. This is an indication of profitability of the investment under these alternative scenarios as their values are greater than 1 and the discount rate of 0.1 threshold values respectively for BCR and

IRR (Table 2.1). The BCR and IRR values for the climate change scenario (Alt.2) are below the threshold values and not profitable.

A look at the full distribution of the BCR values shows that, although Alt.1 and Alt.3 are profitable and feasible on average, there is a relatively high probability (30%) of potential loss and non-feasibility of the scenarios (Figure 2.4). These findings are also supported by the results of the ending cash reserves (EC) estimated over 5 years forecasting period. The EC results show a 3% probability of being negative for Alt.1 under solar pump and no climate change scenario while this probability stands at about 70% for Alt.3 under solar pump, purchase and no climate change scenarios. As for the baseline and climate change (Alt.2) scenarios, the probability of having a negative ending cash reserves is between 90 and 92 percent (Appendix 2.B). This outcome is mainly driven by higher production costs (input and capital costs) that are recorded due to labor.

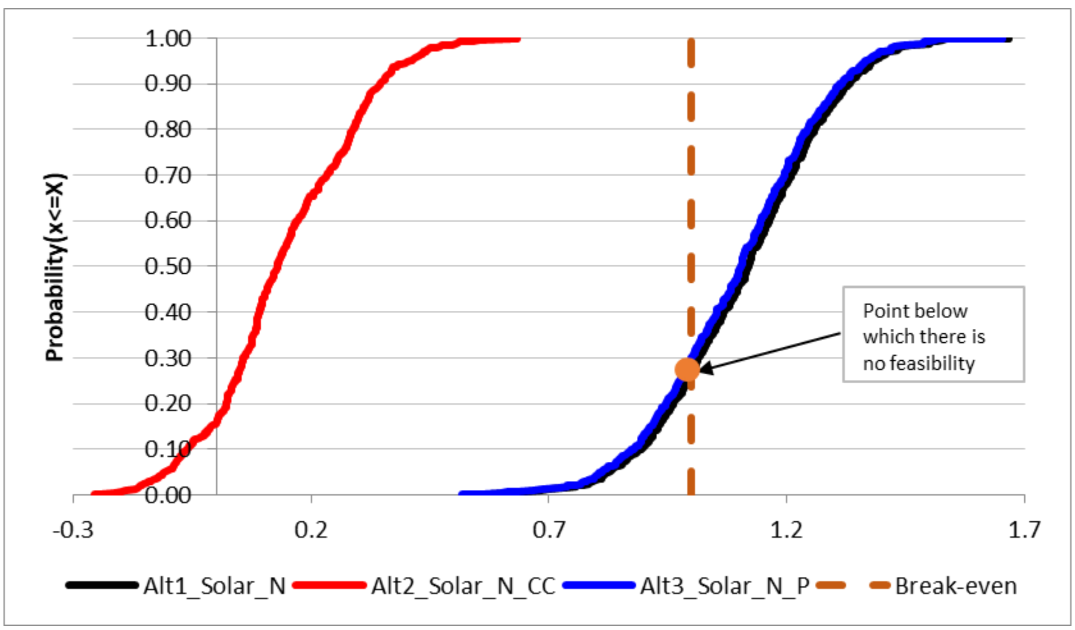

Figure 2.4. Cumulative distribution of the benefit cost ratio for alternative scenarios

5.2.*Household nutrition simulation*

We evaluate nutrient contents from food consumption and compare them to daily minimum requirements per adult equivalent (AE), to determine adequacy in calories, proteins, fat, calcium, iron, vitamin A, zinc, vitamins B9 and B12 intakes available to the household. In this analysis, farm families consume food grown on the farm and/or purchased at the market for their nutrition. A preliminary analysis of food items consumed by households in Robit using a household diet diversity score (HDDS) approach based on a simple count of food groups (Kennedy et al., 2013) indicates a predominance of a cereal-based diet with substantial shortage of animal-source products consumption. A specific scenario (Alt.3) was added to evaluate the impacts of purchasing animal source foods (ASF) on availability of nutrients, including micronutrients (zinc, vitamins B9 and 12), and improvement of nutrition at the household level.

The ability to purchase supplemental food stuff was based on the amount of profit available and nutritional needs. Households in alternatives associated with solar pumps and no climate change scenarios (Alt.2, Alt.3) were allowed in the model to use on average 66% of their profit to purchase food for nutrition improvement with a priority for food of animal origin. Beef, eggs and milk were targeted during the purchase to complement the consumption of on-farm production that was increased due to improved livestock productivity related to fodder feeding. Households under the baseline scenario did not have available cash to purchase enough supplemental foods due to low profit and relied mainly on their own production. Minimal food purchase was made under the climate change scenario alternative (Alt.2) due to low profit levels. Research has shown that a better socio-economic status is key to increasing food diversity and security at the household level (Kennedy et al. 2013).

Simulated levels of nutrients available to farm families increased substantially in the alternative scenario associated with increased purchase (Alt.3) compared to other alternative scenarios and the baseline. For instance, simulation results show that the amount of milk consumed by families in Robit kebele increased almost 8-fold in alternative scenario Alt.3 associated with feeding native cow, food purchase and no climate change effect compared to the baseline scenario (Appendix 2.C). The number of eggs consumed increased 2.8 times while the quantity of beef consumed increased almost 50-fold under Alt.3 scenario compared to the baseline. Half of the increase in beef consumption in Alt.3 is also due to increased levels of on-farm production and consumption of beef as a result of improved livestock technologies. The baseline data indicated that the level of consumption of beef produced on farm was very low (two kilograms per year per household) while the increase in production and purchase of beef under Alt. 3 led to a sharp increase in consumption of 106 Kgs of beef per year and household. Simulation results for each of the nutritional variables are presented and discussed below in details (Table 2.2 and Appendix 2.C).

Table 2.2. Nutritional impacts of livestock technologies in Robit kebele

		Baseline	Alt.1-Solar_N	Alt.2-Solar_N_CC	Alt.3-Solar_N_P	% Increase in Nutrient: Base, Alt2/Alt3	
Nutrition:	Min req.	Average daily nutrients in year 5				*Base/Alt3*	*Alt2/Alt3*
Energy (calories/AE):	2,353	2,483	2,899	2,534	3,856	**55%**	**52%**
Proteins (grs/AE):	41.2	54.2	63.5	55.7	76.6	**41%**	**37%**
Fat (grs/AE):	51	28	32	28	144	**412%**	**407%**
Calcium (grs/AE):	1	0.12	0.16	0.13	0.30	**158%**	**127%**
Iron (grs/AE):	0.009	0.017	0.020	0.017	0.020	**20%**	**17%**
Vitamin A (µg RAE/AE):	600	433	1,406	639	1149	**165%**	**80%**
Zinc (mg/AE):	8.1	15.5	18.1	16.1	25.0	**62%**	**56%**
Vitamin B9 (µg/AE):	320	268	320	285	327	**22%**	**15%**
Vitamin B12 (µg/AE):	2	0.18	0.23	0.21	3.27	**1,726%**	**1,438%**

Note: AE = Adult equivalent; grs=grams; Unit for vitamin A = µg RAE/AE: microgram retinol activity equivalent (RAE) / day /person; Min req. = Minimum requirements; Base, Alt.2/Alt.3 = increase from baseline and alternative Alt.2 (related to climate change) to alternative scenario Alt.3 (purchase); numbers in red show nutrient deficiency

Overall, the nutrition simulation results show that the food products consumed by families in the potential alternative scenarios met the minimum daily requirements for calories, proteins, iron, vitamin A, and zinc but were insufficient for calcium, fat, vitamins B9 and B12 for most of the scenarios (Table 2.2 and Appendix 2.C). Large deficits are associated with calcium for which averages range from 0.12 – 0.30 grams per day per adult equivalent (AE) and are below one gram daily minimum required per AE. A close look at calcium intake probability distribution from simulated values indicates a zero probability for calcium to be greater than the minimum required. Two previous nutrition studies for Ethiopia using FARMSIM have as well shown persistent deficiency in calcium (Bizimana & Richardson, 2019; Bizimana et al., 2020).

The large deficiencies in calcium may be due to two main reasons. First, there is an issue of low consumption of animal products rich in calcium in developing countries (vs. developed countries) (FAO, 2001b; Agueh et al., 2015). Second, there is still discussion on the appropriate level of minimum required calcium intake to consider for nutrition analysis as the current threshold of one gram appears to be relatively higher than what a human body normally requires. Another reason could be related to the wide range of calcium requirements between gender and age making it difficult to find an acceptable average requirement for an adult equivalent unit used in this study.

Large deficits are also observed for fat in baseline, Alt.1 and Alt.2 scenarios for which averages range from 28 – 32 grams per day and AE and are below the minimum required quantity of 51 grams/day/AE. The deficits in fat are mainly due to the low consumption of animal products such as meat and fat. Only the alternative scenario related to increased animal food purchase (Alt.3) has more than twice the amount of fat required, demonstrating again the importance of profit to improve nutrition.

Half of the scenarios, that include the baseline have deficits in vitamin B9 (folate) while all the scenarios, except Alt.3 under the purchase option are deficient in vitamin B12. Folate deficiency can cause anemia and is particularly important for women in childbearing age. Vegetables and legumes are a good source of folate. Vitamin B12 is a trace element with a minimum requirement of two micrograms consumption per day per person but is unavailable in plant-based food and can only be provided through consumption of animal-source food such as red meat, dairy and fish (Ankar & Kumar, 2022). High increase in beef consumption due to production and purchase sharply increased the amount available for vitamin B12 and alleviated the potential deficit in vitamin B12 in alternative three (Alt. 3).

The nutrition results show an improvement in quantity intake available from the baseline to the alternative scenarios for all nutrients (calories, proteins, fat, calcium, iron, vitamin A, zinc, vitamins B9 and B12) and among alternative farming systems associated with no climate change scenarios (Alt. 1 & Alt. 3). It is worth noting the impacts of the increased consumption of products of animal origin such as milk and beef on the increase of nutrients available to the family and their overall nutrition improvement. For example, the potential increase in milk and beef consumption greatly contributed to reducing some of the calcium deficits, increasing its available intake by 1.5 times under alternative Alt.3 associated with increased purchase and no climate change scenario.

Specifically, milk and beef consumption contributed about 62% to the total available calcium while that contribution stands at 15% in the baseline scenario.

Deficits in fat were fully addressed due to the increase in consumption of beef through purchase and production under alternative Alt.3 associated with no climate change and purchase scenario. The increased production, purchase and consumption of beef at the household level in Alt. 3 increased the available fat intake 4-fold in comparison to the baseline and the alternative under the climate change scenario (Alt.2) (Table 2.2). The contribution to available fat intake from increased beef consumption varied from 0.02% in baseline to 78% in alternative scenario Atl.3 due to increased beef purchase and production. Note that, under a strong assumption, the beef consumption fraction under Alt.3 was increased to 10 percent compared to 0.04 percent consumption of on-farm production of beef reported under the baseline by household survey. Likewise, the increase in beef production, purchase and consumption raised substantially the available intake quantities of the vitamin B12 under the alternative associated with increased purchase and no climate change scenario (Alt.3) compared to the baseline and the climate change alternative (Alt.2). Available vitamin B12 intakes increased between 14 and 17-fold under Alt.3 compared to the baseline and Alt.2. The increased consumption of beef and milk through production and purchase contributed almost exclusively at 97% to the vitamin B12 total available intake at the household. Although a trace element, deficiency in vitamin B12 can lead to hematologic and neurological problems (Ankar and Kumar, 2022). See table 2.2 above for details in nutrients intake increases.

The nutritional impacts from increased animal products consumption consistently led to the increase in available nutrients under alternative scenarios with improved livestock production technologies and purchase options. This is illustrated by alternative three (Alt.3) under no climate change effect scenario and associated with use of solar pumps for irrigation and native cow feeding. Table 2.2 presents detailed results on the percentage increase in nutrients under Alt. 3 compared to the baseline under current technology use and the alternative under the climate change scenarios. Similar results on nutritional improvements due to improved crop and livestock technologies were observed in a recent study in Amhara region of Ethiopia but the income path to better nutrition stood out compared to the production (Bizimana et al., 2020). Also, a study on the impacts of small-scale irrigation on household dietary diversity in Ethiopia and Tanzania showed that potential pathways to food diversity was most likely through increased income rather than directly through production (Aseyehegn et al., 2012; Passarelli et al., 2018). Similar outcome in a study in Sub-Saharan Africa indicate that irrigation systems improved the consumption of food products of animal origin and nutrition due to potential increases in income and improved livestock productivity from feeds (Domènech and Ringler, 2013).

Although this study focused on the impacts of feeds on livestock production and improved human nutrition at the household level with and without climate change effects, there are still several constraints related to fodder production and adoption in Ethiopia (Bezabih et al., 2016; Abeyou et al., 2021). However, according to the study on vetch and oats feeds in Ethiopia by Bezabih et al. (2016), farmers acknowledged that the use of small-scale irrigation is one of the remedies to land shortage and production of quality animal feeds. This statement is corroborated by the findings of this integrated study which found that the impacts of climate change on fodder production was mitigated by the use of irrigation.

6. Conclusions and recommendations

An integrated approach is used to assess the outcomes and impacts of improved livestock production technologies on the socio-economic and resilience of households in Ethiopia, in the context of climate variability. In this study, we simulated short and long-term production and use of irrigated fodder as a feed through improved small-scale irrigation technologies, agricultural land and input use. Four scenarios are analyzed and comprise a baseline scenario and three alternative scenarios that include a scenario under climate change impacts and two under no climate change impacts and purchase options.

Even though the levels of profits are low due to increased cost of production for all scenarios, the simulation results show the feasibility of the alternatives under no climate change scenarios with higher profits compared to the baseline scenario. The alternative under climate change scenario is profitable compared to the baseline scenario but it is not feasible in the short term. Simulated households under improved small-scale irrigation technologies and no climate change alternative scenarios generated more income than their counterparts in the baseline and climate change scenarios. In addition, the use of improved livestock production technologies (feeds) increased livestock production in terms of milk and meat at the household level. The consumption of more milk and beef due to production and purchase led to more available nutrient intakes and improved significantly the nutrition at the household level under the food purchase alternative. Results show that the increase in animal products availability and purchase can potentially lead to higher consumption of animal products at the household level and increase nutrient intake for better nutrition. Adopting improved agricultural and livestock technologies has a high potential to improve economic and nutritional wellbeing and resilience in the face of climate variability in Ethiopia and an opportunity to meet its goals of economic development and food security. However, choosing among the income or production paths to improve nutrition can be a difficult choice to make for households. More study and field research on the impacts of climate variability to confirm current results and study the factors that affect the decision to choose among the options to improve nutrition need to be explored in future studies.

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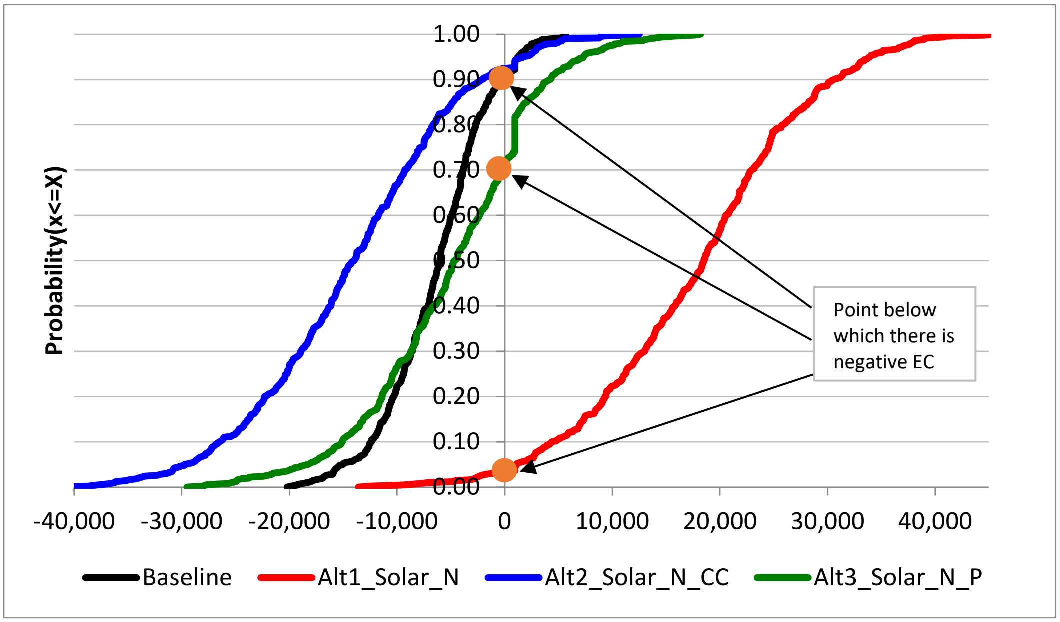
Appendices

Appendix 2.A. Mean crop yields (Kg/ha), land area (ha) and input costs (Birr/ha) for scenarios in Robit kebele

	Baseline scenario						Alternative scenario 3 (Solar pump and food purchase)					
Crops	Mean yield (Kgs/ha)	Area planted /Household (ha)	Cost fertilizer (Birr/ha)	Cost seed (Birr/ha)	Cost irrigation labor (Birr/ha)	Other labor cost (Birr/ha)	Mean yield (Kgs/ha)	Area planted /Household (ha)	Cost fertilizer (Birr/ha)	Cost seed (Birr/ha)	Cost irrigation labor (Birr/ha)	Other labor cost (Birr/ha)
Teff	988	0.06	2,998	363	0	1,250	988	0.06	2,998	363	0	1,250
Maize	2,469	0.32	4,992	476	0	854	2,469	0.32	4,992	476	0	854
Millet	1,576	0.32	2,730	71	0	860	1,576	0.32	2,730	71	0	860
Tomato	14,293	0.03	74	420	6,740	6,292	21,714	0.07	74	600	10,757	6,292
Cabbage	8,420	0.01	110	880	258	0	18,089	0.01	110	880	10,757	0
Chickpeas	1,274	0.01	358	122	258	0	1,274	0.01	358	122	258	0
Fodder (oats & vetch)	12,654	0.04	33	1,200	258	1,365	34,168	0.1	1,500	1,200	6,024	1,365
Napier grass	10,936	0.02	1,500	1,000	4,800	0	21,840	0.04	2,522	5,000	25,200	0

Appendix 2.B. Cumulative distribution function of ending cash reserves, Robit



Appendix 2.C. Food of animal origin consumed per year at village and household level, Robit

	Baseline scenario		Alternative scenario (Alt3.: Purchase)	
Food items (in Kgs)	Raised	purchased	Raised	purchased
<u>Village level (1983 HH)</u>				
Milk in KG	38,832	0	57,424	277,620
Eggs in KG	2,484	7292	2,484	24,986
Chicken in KG	3,869	0	3,869	0
Beef in KG	3,086	0	11,357	198,300
Lamb in KG	1,617	0	1,617	0
Goat Meat in KG	27	0	27	0
Pig Meat in KG	0	0	0	0
Butter in KG	2,710	0	1,779	0
<u>Household level (1 HH)</u>				
Milk in KG	20	0	29	140
Eggs in KG	1	4	1	13
Chicken in KG	2	0	2	0
Beef in KG	2	0	6	100
Lamb in KG	1	0	1	0
Goat Meat in KG	0	0	0	0
Pig Meat in KG	0	0	0	0
Butter in KG	1	0	1	0

<u>**Note**</u>: Information was summarized from a household survey data collected by IFPRI (2017); HH = household.