FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Innovation Laboratory for Small Scale Irrigation

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Submitted by the Norman Borlaug Institute for International Agriculture and Development, The Texas A&M University System & AgriLife Research

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USAID FROM THE AMERICAN PEOPLE | THE BORLAUG INSTITUTE | TEXAS A&M AGRILIFE RESEARCH | THE TEXAS A&M UNIVERSITY SYSTEM | IFPRI INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE | IWMI International Water Management Institute | ILRI | World Vegetable Center | HWISE-RCN

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Executive Summary

The Innovation Lab for Small Scale Irrigation (ILSSI), a cooperative agreement led by the Borlaug Institute at Texas A & M University, made significant progress on ***Objective 1, Identify and Test Approaches to Sustainably Scale (Small Scale Irrigation) SSI through Reducing Constraints and Strengthening Opportunities for Access***. ILSSI activities to identify scaling opportunities and pathway is yielding evidence on the irrigation equipment market and initial insights into improving market density and competitiveness to benefit small scale farmers. Net-Map activities in Ghana, Ethiopia, and Mali reflect the relatively strong role of a small number of actors in the public sector and low influence of smallholder farmers themselves. Private partners achieved milestones on marketing plans, distribution network establishment, mobile money payment systems, and credit scoring tools. The private partner in Ghana began solar pump sales, but were below target, so quickly adapted marketing to reach poorer farmers. Solar pump clients are distributed throughout the country and solar pumps are being used for horticulture, cocoa, livestock, fish farming and domestic uses. As many of the private companies have not done extensive market research and have little capacity on water, the companies have utilized the solar irrigation suitability maps, market segmentation, refined tools for asset-based finance and other information produced and shared by ILSSI through multi-stakeholder dialogues and direct engagement. Recent study results related to markets and scaling include: constraints on both supply and demand for credit; credit and access to groundwater are key factors for farmers to invest; price margins vary by country's tangible and intangible costs; companies that receive de-risking support from donors have lower margins and therefore, lower prices to customers.

Toward ***Objective 2, Identify and test approaches to scale SSI to be sustainable and support resilience****,* ILSSI climate and water resource analysis in West Africa shows limitations for rainfed crops and need for supplemental and dry season irrigation. Water Accounting for Mali quantified the limits and opportunities to develop water resources for agriculture. While crop insurance based on yield index could offer a tool for resilience, but products need to be strengthened to increase payouts and ensure farmers actually benefit when needed. At the same time, analysis shows Sub-Saharan Africa is at high risk for agro-chemical related pollution with intensification. Quantitative analysis on de facto multiple use of irrigation water resources shows irrigators have better water access for WASH, but other factors often prevent improved health outcomes. In addition, results of the Mali survey suggest higher income, more productive of fruits and vegetables, and greater resilience for irrigating households. Domestic production of vegetable seed through irrigation holds high potential for farmer incomes and improvement of market supply of seed to meet the high demand, but regulatory structures block the formal growth of local seed production.

Achievement on ***Objective 3, Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production***, was the negatively affected by limits on in-person interaction in the field. ILSSI worked with private companies on approaches to reach more women and resource-poor farmers, particularly refining credit scoring and assessment tools and market segmentation to be more gender responsive. We also began to analyze gender relations in the irrigated fodder value chain to assess potential impact on women, as irrigated fodder markets become increasingly commercial. In addition, ILSSI restarted fieldwork to work with farmer groups on water governance issues with pilots on local level approaches in Ethiopia and Ghana. We made progress on analyzing the spread of farmer-led irrigation in policy and institutions and developed a database of SSI projects. Finally, ILSSI continued analyzing, publishing, and knowledge sharing on the linkages between irrigation, specific irrigated value chains, and nutrition.

Despite limited in-person engagement, ILSSI continued activities on **Objective 4, Achieve impact through uptake of ILSSI research results and methods**. ILSSI research-based evidence was shared through numerous platforms and events; ILSSI researchers organized and/or were invited to national and global forums targeted at policy makers and investment planners, including with the African Union, World Bank, and UN Working Group on Nutrition. Research results have been included in two new guidelines on SSI (World Bank; IFC and IFAD). National multi-stakeholder dialogues were convened in all project countries; WSG2030 joined the Ethiopia platform as a partner. General knowledge sharing, communications and outreach efforts were strengthened through an improved website and quarterly newsletter. ILSSI established a publication repository with the TAMU library to ensure continued accessibility. HICD declined initially, but trainings resumed with appropriate protocols; private partners began trainings on solar irrigation for a range of stakeholders and producers. Innovative approaches to HICD included Innovation Scholarships/Internships and Hackathon.

During the reporting period, ILSSI added **Objective 5, Assessment of the benefits of Bureau of Humanitarian Assistance (BHA) investments watershed rehabilitation and irrigation in PSNP woredas of Ethiopia,** through a buy-in of the Bureau of Humanitarian Assistance (BHA). IFPRI and the IDSS team are using quantitative and qualitative data, and models, and initial results indicate BHA's investments in PSNP had positive outcomes in Ethiopia.

Summary of key FTF Indicators

Indicator	**Description**	**Number**
STIR-12	Number of peer-reviewed scientific publications resulting from USG support to Research and implementation programs	21
EG.3.2	Number of individuals participating in USG food security programs	2658
EG.3.2-1	Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training	2147
EG. 3.2-2	Number of individuals who have received USG-supported degree-granting agricultural sector productivity or food security training	15
EG. 3.2-24	Number of individuals in the agriculture systems who have applied improved management practices or technologies with USG assistance	254
EG.3.2-7	Number of technologies or management practices under research, under field testing, or made available for transfer	3
EG.3.1-14	Value of new USG commitments and private sector investment leveraged by the USG to support food security and nutrition	$1,454,979
EG.3.2-27	Value of agriculture-related financing accessed as a result of USG assistance	$216,728
GNDR-2	Percentage of female participants in USG-assisted programs designed to increase access to productive economic resources [IM-level]	24.63%
Youth-3	Percentage of participants in USG-assisted programs designed to increase access to productive economic resources who are youth	1.14%

1. Introduction

The Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI) is a cooperative agreement led by the Norman Borlaug Institute for International Agriculture Development at Texas A & M University (TAMU) Agrilife Research. ILSSI's vision is to contribute to an increase of profitable, sustainable and gender-sensitive irrigation to support inclusive agricultural growth, resilient food systems, and nutrition and health outcomes, particularly for vulnerable populations. The project works in Ethiopia, Ghana, and Mali, with buy-in activities supported by the Bureau for Humanitarian Affairs in Ethiopia and Mali; limited analysis of data continues for Tanzania. ILSSI works in collaboration with the International Water Management Institute, International Food Policy Research Institute, International Livestock Research Institute, the World Vegetable Center, Kwame Nkrumah University for Science and Technology, and private sector partners PEG Africa (Ghana), Rensys Engineering (Ethiopia), and EMICOM and Ecotech Mali (ETM) (Mali). This report describes progress toward objectives in fiscal year 2021, the eighth year of ILSSI's cooperative agreement.

2. Progress toward objectives (based on components of Areas of Inquiry)

Objective 0: Effectively plan, coordinate, and organize multi-institutional activities

Activity 0.1. Initiate and manage project activities

- Management Entity (ME) at TAMU oversaw project activities, maintained 7 sub-agreements, and leveraged several unfunded collaborations.
- ME engaged a Project Coordinator to support M & E, reporting, partnerships, and communications.
- Budget burn rate has improved with stronger monitoring of sub-agreement expenditure rates.
- Convened virtual Project Management Committee meetings, quarterly External Advisory Committee meetings and semi-annual research meetings.
- ME engaged virtually with the USAID Missions in Ghana, Ethiopia and Mali; Mission representatives attended ILSSI workshops; engaged Mission supported projects (Mali, Ghana, Rwanda and Malawi).

Activity 0.4. New funding engagement and initiatives

- ILSSI is an unfunded partner in a new USAID West Africa project for soy and maize for poultry feed production. IDSS analysis was used on the potential for irrigation in the target zones of influence.
- ILSSI ME and IDSS team are participating in the USAID supported Sene Yiriwa project in the Inner Niger Delta in Mali. ILSSI ME shared relevant research results/resources on water resources, gender and governance, while biophysical physical modelers will contribute to environmental assessment.
- ILSSI is a technical partner in the recently awarded Horticulture Innovation Lab with UCDavis.
- Despite extensive groundwork and partnership development, ILSSI did not get a sub-contract under the Malawi USAID flagship program Agriculture Diversification (AgDiv).
- ILSSI researchers began work in Nepal under a complementary activity with the Cereal Systems Initiative for South Asia (CSISA) under a USAID Mission buy-in to the International Maize and Wheat Improvement Center (CIMMYT).

Objective 1: Identify and test approaches to sustainably scale SSI through reducing constraints and strengthening opportunities for access

Activity 1.1: Identify upscaling opportunities for resilient SSI systems

Sub-Activity 1.1.1. Joint research scaling activity with private sector entities

ILSSI's private partners have made progress against milestones and offer lessons relevant to scaling and market development; a more detailed description is provided in Annex I. Private sector partnerships: Progress toward milestones and key lessons. In summary, partners are:

- Adapting their marketing and distribution approaches to reach women and the poorest farmers
- Adapting credit scoring tools to contextual factors and to be more gender sensitive
- Taking on more roles, include educating farmers on financial literacy and agronomy, to acquire more clients and support repayment
- Finding clients want pumps for mixed purposes, including fruits, vegetables, poultry, livestock/dairy and fish farming
- Forming partnerships with related services and suppliers (borehole, pipe/sprinkler suppliers)
- Finding mixed results in efforts to partner with produce off-takers

In addition, IWMI co-leveraged AfricaRISING and Partnering for Green Growth (Ethiopia), and Pumptech (Ghana) toward strengthening demand-supply linkages along the scaling pathway.

PEG CLIENT 'GROWING GOLD' REDUCED COSTS BY REPLACING HAND WATERING WITH SOLAR PUMP AND INVESTED THE SAVINGS INTO DRIP AND REGENERATIVE PRACTICES. (PHOTO: ILSSI)

Sub-Activity 1.1.2. Qualitative survey with private and public sectors to assess information requirements and format

IWMI assessed the spatial and market information needs for enabling public and private sector investment and interventions toward scaling, outlined in 'Enabling private and public sector investment into farmer-led irrigation: What information is necessary?'. Results show information needed for a company's decision to develop and/or expand their products and/or services in a country:

- Water and energy: Availability and quality of water sources (75% respondents); network of renewable and non-renewable energy sources (75%) as critical to decisions.
- Farm level information: Farm specifications (e.g., size, location, crop's specific information, and irrigation system) (73%); presence of farmer cooperatives, unions, other social structures (61%).
- Market information (66%): Need for irrigation and demand for irrigation products and services, farmers' financial capacity, farming systems and farming capacity, and the cash-flow possibility to get irrigation investment started.

Sub-Activity 1.1.3 Refining the suitability mapping framework for solar and SSI packages at national scale (Ethiopia and Ghana) and sub-national scale (Ethiopia); Sub-Activity 1.1.4 Validation of the suitability maps using available data from private sector piloting

IWMI collaborated with PEG Africa, Rensys, Pumptech, Solarworks, TechnoServe, and P4G to further refine the interactive online tool (http://sip.africa.iwmi.org/) to assess land suitability for photovoltaic-based irrigation, available resources, and markets. The maps have been adapted for the national context to include distribution center proximity and integrated IFPRI's solar-diesel comparison. The tool has been shared with and used by USAID supported projects in Rwanda, Zambia and Mali, as well as private solar pump companies in Ghana, Ethiopia and Mali. IWMI customized the solar suitability maps to the PEG Africa and Rensys products and geographical distribution areas. Stakeholder feedback on customization noted need to overlay agricultural activities, demand, sales, and technology performance.

Sub-Activity 1.1.6. Develop irrigated fodder suitability map; Assess potential to scale fodder production in Ethiopia

Under a jointly funded activity with the Livestock Systems Innovation Lab and ILRI, the Integrated Decision Support System (team) team (biophysical spatial sciences and socio-economic modelers) estimated the potential to produce biomass, available water resources and irrigation water requirement for Napier, oats, vetch and alfalfa using small scale irrigation in rainfed agricultural lands. Results indicated that a substantial amount of fodder biomass (e.g., up to 78 ton/ha of Napier grass in the most suitable areas and optimal biophysical climatic years) can be produced in the usual rainfed lands during the dry season. In the majority of the rainfed agricultural areas, the available water resources (i.e., surface runoff generated and groundwater recharge) were more than the irrigation water requirement to cultivate fodder during the dry season (See Annex 2. Assessing the potential to scale fodder production in Ethiopia). A webinar shares results targeting stakeholders in Ethiopia, the USAID Mission and IFAD. Adding to this study, IFPRI completed an in-depth analysis of the potential for adoption of irrigated fodder in Ethiopia. A policy brief will be published in early 2022.

Sub-Activity 1.1.7.a. Land suitability assessment for cocoa cultivation in Ghana using a GIS based Multi-Criteria Evaluation (MCE)

Based on stakeholder consultation, ILSSI found that cocoa productivity has been declining in Ghana due to a lack of sufficient water and that farm rehabilitation is hindered by 40% loss of seedlings due to unreliable rainfall. Cocoa remains central to Ghana agriculture exports, foreign exchange earnings, and direct and indirect employment and income. Using biophysical analysis (SWAT and APEX), ILSSI researchers completed an initial suitability assessment for irrigated cocoa (See Annex 3. Suitability Analysis for Cocoa Production), which suggests most cocoa growing areas have insufficient rainfall to sustain production.

Sub-Activity 1.1.7.b. Potential of small scale irrigation and improved soil management practices on cocoa production, income and nutrition in Ghana

The socio-economic study for cocoa production protocol has been developed, approved by the TAMU IRB, and will be implemented in the Ashanti and Western regions in Ghana in FY2022. A standard household survey questionnaire will be used in the study and administered by enumerators from the Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana.

Activity 1.2: Identify constraints and assess impact of policy through analyses and dialogue

Sub-Activity 1.2.1. Constraints Analysis

The IFPRI paper on constraints to the adoption of SSI technologies (Hierarchical modelling of the constraints to irrigation adoption in Ghana, Ethiopia, and Tanzania) received a positive review from the *Water Economics and Policy* journal.

Sub-Activity Activity 1.2.2: Role of credit constraints

IFPRI discussion paper titled: "Are Smallholder Farmers Credit Constrained? Evidence on Demand and Supply Constraints of Credit in Ethiopia and Tanzania" has been revised and submitted to *World Development*. IFPRI used primary survey data from Ethiopia and Tanzania to examine the nature of credit constraints facing smallholders and the factors that affect credit constraints, as well as gender-differentiation. Results show that demand-side credit constraints are at least as important as supply-side factors in both countries, and women are more likely to be credit constrained (from both the supply and demand sides) than men. This suggests that policies and interventions should focus on addressing both supply- and demand-side credit constraints, including through targeted interventions to reduce risk, such as crop insurance and gender-sensitive policies to improve women's access to credit. The study highlights the demand-side constraints that are often ignored.

Sub-Activity 1.2.3. Net-Mapping in Ethiopia and Ghana to understand private sector constraints

IFPRI discussion paper on the Ghana Net-mapping : "Smallholder Irrigation Technology Diffusion in Ghana Insights from Stakeholder Mapping" notes a wide variety of actors from government, the private sector, international organizations and funders, research organizations and NGOs involved in the diffusion of SSI technologies. At the national level, diffusion of SSI technologies is considered to be largely influenced by the Ghana Irrigation Development Authority together with private sector actors focused on importation, distribution and financing of technologies. However, farmers are considered to have no influence over the diffusion of SSI, suggesting that SSI is largely considered a supply-driven process. In contrast, decentralized actors in northern Ghana identified farmers as key influencers, although participants noted that much of this was *potential* influence as opposed to actual, as well as a larger and more diversified set of government stakeholders that act as regulators and gatekeepers. For irrigation diffusion to successfully move from importation/distribution to benefiting smallholder farmers, all actors have to come together to better understand farmers' needs and challenges. The ILSSI multi-stakeholder platform can help actors in the sector refocus on farmers as clients and end users.

Sub-Activity 1.2.4. Stakeholder analysis and mapping of actors in SSI scaling pathway (completed in FY2020)

Sub-Activity 1.2.5. Microeconomic study of the effect of loans and tax breaks on the demand for different SSI types

IWMI draft paper on 'Price, credit or uncertainty? Increasing small scale irrigation (SSI) in Ethiopia' based on a survey of 400 households shows that farmers' irrigation adoption decisions are most sensitive to the availability of loans, and the removal of ambiguities around well drilling. Prices of pumps affected irrigation equipment adoption to a smaller effect than these two factors. These results suggest that public subsidies may need to be tailored to context in Ethiopia. The study highlights that reducing ambiguities (particularly around boreholes for groundwater) will be vital for expanding SSI; public investment options to support scaling may look at alternatives to pump subsidies.

Sub-Activity 1.2.6. Assess impact of change in cost of water lifting technologies related to reduction in tariff on producer revenue

IDSS FARMSIM model analysis: "Preliminary economic impacts assessment of tariff reduction on water lifting technologies in Ethiopia", provided an ex-ante assessment of SSI water lifting technologies (fuel and solar pumps) with and without an import tax exemption. Results showed that the reduced tariff could reduce cost of the irrigation technologies (tools and equipment) and enable farmers to invest in technology profitably, and may increase potential for loan access while reducing overall credit costs.

Sub-Activity 1.2.7. Facilitating dialogue between key stakeholders to strengthen SSI scaling

IWMI and other co-convenors organized 3 multi-stakeholder dialogues in Ethiopia, Ghana and Mali:

- Ghana: 'Understanding the scalability of solar-powered irrigation in Ghana: market segmentation and mapping pump suitability' (44 participants)
- Ethiopia: 'Value Chain Approaches to Small Scale Irrigation Development' with 2030 WRG, World Bank, Agricultural Water Management Task Force, Ministry of Agriculture (51 participants, 20+ organizations)
- Mali: 'Multi-stakeholder dialogues supporting the scaling of ecological inclusive and sustainable agricultural water management (ISAWM) in Mali' with Safeguarding Sahelian Wetlands for Food Security (SAWEL) (35 participants)

Activity 1.3: Identify entry points to reduce supply constraints on irrigation technology markets

Sub-Activity 1.3.1 Determination of marketing margin along different points of SSI chain of actors in Ethiopia and Ghana

Ethiopia - Analysis of cost build up on water lifting and irrigation equipment initial results:

- Supply chain for irrigation technologies is oligopolistic and uncompetitive with limited distribution networks or repair and maintenance services.
- Short supply chain: Suppliers perform multiple functions (importing/manufacturing, wholesaling and distributing)
- Marketing margins for irrigation equipment are high. For example:
  - Estimated marketing margin for a range of solar pumps is 12-48%; Grundfos is at 60%.
  - Estimated marketing margin for motor pumps is between 23-50%.
  - Estimated marketing margin for rope pumps is greater than 70%.
- Businesses do no systematic demand assessment of the market. Suppliers/distributors respond to immediate demand, especially government and NGOs.
- Actors in solar and motor pump supply do not directly target small scale farmers.

- Forex regulations reduce import capacity, affect timing, costs (e.g., operational expenses), stock (pumps, accessories)
- Low political commitment to import irrigation equipment may be reflected by: weak implementation of tariff removal, forex regulation, absence of credit products, among others.

Ghana: Analysis of market margin for solar-powered irrigation pumps initial findings:

- Range of gross and net margin of different solar-powered irrigation pumps 40-55% and 10-25%, respectively. Market margin of Lorentz 10-15% lower than Future Pump SF1, Shakti Pump 5.
- Margins include tangible costs (import, storage, transportation, demurrage and waiver filing fees) and intangible costs (bureaucracy, non-adaptation, political and poor collaboration or partnerships).
- Benefits include tangible (economic profit and tax waivers) and intangible (partnerships, visibility, new business opportunities, reputation and new markets).
- Intangible benefits make up a key difference of market margin between Lorentz and Future Pump SF1 and Shakti Pump 5. Specifically, partnership with non-profit institutions such as donors, development organizations, NGOs and research institutes can improve marketing and product visibility (extend access of solar pumps to smallholder farmers, support new business opportunities in the sub-sector, and generate market-related knowledge). Companies with such partnerships lower price margins to expand to larger and more client segments.

Sub-Activity 1.3.2 Identification and piloting of SSI scaling pathways with private entities; Assess whether the piloted finance modality/business model reaches different types of farmers

IWMI leveraged activities with AfricaRISING to identify value pathways for SSI scaling in Ghana through a knowledge partnership with Pumptech Ghana (Lorentz PS2 pump distributor). Market segmentation found four segments based on: water amount needed, available resources, pump preferences and capacity to pay. Results were shared through the ILSSI supported multi-stakeholder dialogue platform.

Sub-Activity 1.3.3. Assess blocking and enabling mechanisms and develop systematic scaling approaches for Ghana and Ethiopia

IWMI article 'Towards adaptive scaling of contemporary farmer-led irrigation development: A conceptual framework' argues that farmer-led irrigation development (FLID) is recognized as being critical to food security and climate resilience in sub-Sahara Africa, but expansion remains modest. The paper looks at the multifaceted contexts and attributes of FLID: entrepreneurship, heterogeneity, capitalization, collaboration, politicization and dynamism.

Sub-Activity 1.3.4: Estimating the potential of solar pumps in improving irrigation access vis a vis energy intensity

IFPRI published a paper associated with ILSSI on the potential of solar versus diesel irrigation and also published a blog on the same. The study finds particularly large potential in southern and central Africa.

Activity 1.4: Identify entry points to reduce constraints and strengthen irrigated fodder markets

Sub-Activity 1.4.2. Conduct cost-benefit analysis of irrigated fodder production

ILRI collected data for a cost-benefit analysis of irrigated fodder, and fodder market surveys have been completed. Data analysis and research report writing is underway. COVID-19 and local security issues affected the planned work.

Objective 2: Identify and test approaches to scale SSI to be sustainable and support resilience

Activity 2.1.: Assess tradeoffs between environmental and human resilience to climate shocks and stressors

Sub-Activity 2.1.2. Irrigation and water pollution analysis

Two analyses were completed. The empirical analysis used household survey data collected from four woredas in Ethiopia and showed that irrigated crop production may indeed raise the consumption of fertilizers; but this effect is mainly achieved through increased cropping intensity in annual crop production. Irrigation helps extend the annual crop cultivation into the dry season, which in turn leads to increased fertilizer consumption. (See Annex 4. Irrigation and water pollution analysis).

Findings from the first analysis called for an ex-ante assessment of the implications of increased fertilizer use on water pollution. IDSS results show that SSI may decrease soil erosion due to formation of cover crops during the dry season, and there may be a reduction in total phosphorus loading due to consumption of residual phosphorus from the rainfall season by dry season crops. However, the total nitrogen loading may increase with additional use of nitrogen-based fertilizer for the dry season crops, as well as fixation of nitrogen in the case of legume irrigated crops (e.g. Vetch).

The results of the modeling analysis overall show that an expansion of SSI in Ethiopia may create hotspots with elevated water nutrient pollution risk. The results from the study serve as evidence that irrigation development in Ethiopia, or more broadly in Sub-Saharan Africa, has impacts on the environment that go beyond traditional environmental impact assessments. More efforts need to be taken to ensure the environmental sustainability of SSI development. The paper is under review with *Agriculture, Ecosystems and Environment*. A major challenge to the study was identifying appropriate water quality data.

Sub-Activity 2.1.3.a. Assess future climatic risk on water availability and crop production

The IDSS team continued to work on climate assessment in West Africa. The climate change data for Ghana was downscaled from multiple Regional Climate Models (RCMs), and bias corrected using locally collected data. Using daily bias-corrected RCM and observed rainfall and maximum/minimum temperature data, climate and weather extreme indices were estimated based on the Expert Team for Climate Change Detection Indices (ETCCDI). The climate and weather extremes will be used to identify strategies to build resilience against such climatic shocks. This links with Sub-Activity 1.1.7 on land suitability analysis for cocoa in Ghana. (See Annex 5. Assess future climatic risk on water availability and crop production.)

2.1.3.c. Potential of small scale irrigation and improved soil management practices on cocoa production, income and nutrition in Ghana

ILSSI researchers engaged with the cocoa extension system in Ghana, recruited an intern to work with PEG on a cocoa market segment business model, developed a sub-agreement with KNUST, identified potential farms with ECOM Trading, and completed a protocol to collect socio-economic data on cocoa production. Data collection and analysis will be completed in the next fiscal year.

Sub-Activity 2.1.5 Assess potential trade-offs in irrigated fodder production

Sub-Activity 2.1.6 Validate alternative irrigated forage options for different contexts

ILRI analyzed data from 350 household interviews (half of whom are adopters and the others non-adopters) and qualitative data from key informant interviews and farm level inventories. Results indicate a significant difference in milk production and farm income. Adopters of irrigated fodder produced on average 5.1 Liters of milk per day per cow, whereas non-adopters produced 1.35 Liters per cow. Difference is attributed to use of improved lactating cows and cultivated fodder. The majority of irrigated fodder producers own crossbred cows; an incentive for farmers to practice irrigated fodder development, because improved cows need good quality fodder and supplements to meet nutrient demands. Considerable economic and livelihood gains are associated with use of irrigated fodder, but it leads to increased competition for land and water resources. In some cases, limited water available from shallow wells appeared to also limit expansion. Notably, irrigated fodder requires less water, labor, and other inputs, such as no pesticides, compared to irrigated vegetables and Khat production, so irrigated fodder adoption has minimal environmental trade-off. Compared to other irrigated crops in the area, less water and other inputs of fodder provides a considerable gain in farm income and household nutrition.

GRADUATE STUDENT COLLECTING DATA IN ROBIT BATA, ETHIOPIA. PHOTO CREDIT, ILRI.

Activity 2.2.: Assess approaches to reducing risks associated with irrigation investments

Sub-Activity 2.2.1: Climate risk assessment; Sub-Activity 2.2.2: ENSO assessment, Ethiopia

IFPRI's paper on the impact of the 2015/2016 ENSO weather anomaly on irrigating and rainfed farmers in Ethiopia related to climate resilience has been readied for submission to *Agricultural Economics*. No statistically significant differences in maize yield, total value of production, daily food expenditures, and HDDS (Household Dietary Diversity) were found between irrigators affected by the ENSO driven drought and those not affected by the drought. However, at the same time, among rainfed farmers, the drought led to a 39% reduction in yield, a 40% reduction in total value of production, a 13% increase in farmers' daily food expenditure, and a 4% loss in dietary diversity of the household. This suggests that irrigation plays a critical role for climate resilience.

Sub-Activity 2.2.3. Identifying cropping systems (including legume crops, fodder, etc.) that provide the best productivity under different climatic scenarios

ILRI continued screening forage genotypes for water and nutrient use efficiency; graduate students enabled data collection to continue throughout COVID-19, though delays in funding to Ethiopia and problems with after-sales services on the solar pumps were challenges. A total of 15 grass and legume forage varieties from the ILRI Genebank have been established in experimental plots and subjected to irrigation and nutrient input treatments. More than 500 forage and soil samples were collected and analyzed to determine nutritional qualities and soil nutrient dynamics under the different treatment combinations. Preliminary results show large variations among the forage cultivars in biomass yield and overall performance, which will inform the candidate cultivars that would maximize the benefits to smallholders and reduce risks of failure under water deficiencies. Farmers and extension officers are regularly invited to conduct participatory variety evaluation before each forage harvest.

Sub-Activity 2.2.5. Yield-Index insurance and farmers' resilience: premiums and indemnity schedule

The IDSS team developed APEX and FARMSIM integrated yield-based index insurance that can assess the economic and nutritional outcomes of different insurance schemes. The approach strengthens many existing approaches by bringing in crop models in addition to usual rainfall-based indexes. The study included 1) rainfall analysis to classify rainfall regimes that helps to determine high climate risk areas for rainfed cropping systems, 2) APEX model was calibrated and validated for the observed maize yield and used to simulate long-term crop yield, and 3) long-term simulated crop yield and historical rainfall data of case study sites were used to determine the threshold index to trigger payouts based on the expected yield losses. Lemo watershed in Southern Nations Nationalities Region (Ethiopia), and Dimbasinia watershed in the Upper East region (Ghana) were selected as case study sites based on the availability of data and vulnerability to crop failure. The results indicate the best insurance outcomes in Lemo area (Ethiopia) are obtained when purchasing a full yield-index insurance coverage of 100%, but probability of earning an indemnity was zero for an insurance coverage of less than 70%. The study has implications for designing insurance and potential limits/benefits for smallholders. (See Annex 6. Yield-Index insurance and farmers' resilience: premiums and indemnity schedule.)

Activity 2.3.: Assess the potential for innovative technology and scheduling tools to contribute to social-ecological resilience

Sub-Activity 2.3.1. Solar irrigation assessment, sub-national Ghana and Mali

IFPRI conducted a systematic review of availability of input data from national sources which could be used to support the analysis, which led to a refocus on western Africa, specifically Ghana and Mali. IFPRI extended the model to accommodate the variability of weather input data to evaluate the impact of climate change on the economic performance of solar irrigation. Three key climatic variables considered in the analysis are 1) precipitation, 2) temperature and 3) solar irradiance. Simulations have been conducted using downscaled GCM (General Circulation Model) output data under climate change scenarios from CMIP5 (Coupled-Model Intercomparison Project Phase 5). A major challenge to publishing the results of the analysis is a new phase of Coupled-Model Intercomparison Project Phase, CMIP6, is superseding CMIP5, so IFPRI is re-conducting the simulation under CMIP6 scenarios.

Sub-Activity 2.3.2. Estimating the potential of solar pumps in improving irrigation access vis a vis energy intensity

As solar powered irrigation is broadly viewed as a climate smart solution, this IFPRI study will help to quantify the actual potential of this technology given climate risks. Results show solar power is more cost-effective on less than two-thirds of suitable land in Sub-Saharan Africa. While attention is generally on the higher initial capital costs for solar solutions, there are other crucial considerations: Having access to lots of sunlight matters! More than 80% of the area in Southern Africa with irrigation potential could cost-effectively benefit from solar energy. Solar-powered pumps also do well in Central Africa, but other areas of sub-Saharan Africa don't get as much sunlight. Low diesel prices are a disincentive to the adoption of solar-powered motor pumps. In Angola, Nigeria and Sudan, highly subsidized diesel prices – reported in 2018/19 at US$0.44/liter, $0.57/liter and $0.09/liter, respectively – would render solar irrigation profitable only if the installed costs of solar power systems come down to US$0.7–1.8 per watt peak. Lots of rainfall and high humidity do not favor the installation of solar panels (and also depress demand for diesel-powered pumps). While solar insolation is at a maximum around the Equator, higher precipitation levels lower the need for irrigation. Solar powered pumps are more cost-effective for crops with higher irrigation demands, such as sugarcane. While solar panels are sized to meet irrigation demands in the peak months, diesel pump costs increase linearly with irrigation water needs. Connecting the pumps with different water-saving field application technologies, such as drip, does not really affect the effectiveness of either pump type; instead, both technologies would simply be procured at smaller sizes.

Activity 2.4.: Identify pathways from water access and management to improved water and food security, and sustainable resilience (Mali)

Sub-Activity 2.4.1. Irrigation-nutrition linkages assessment Mali

IFPRI was able to restart fieldwork for quantitative and qualitative data collection in February/2021 and complete the survey at the end of March/2021. The draft paper highlights agricultural income and crop diversification. During the dry season, irrigation can reduce vulnerability to erratic rainfall, potentially increasing food security, crop diversification and farmers' income. This study confirms the positive impacts of irrigation on dry season crop income. (See Annex 7. Irrigation-nutrition linkages assessment Mali.)

Sub-Activity 2.4.2. Water Accounting in Black Volta and Upper Niger Basin

IWMI's article 'Assessing water resource availability for expanding smallholder irrigation in the Upper Niger Basin' and project brief and paper on 'Assessing the potential for sustainable expansion of small scale solar irrigation in Ségou and Sikasso, Mali', highlight that Ségou and Sikasso have some of the largest areas suitable for solar-powered irrigation. However, the information on the sustainability of irrigation expansion on water resources is not clearly understood. IWMI combined the outputs from the water accounting plus (WA+), solar suitability mapping, remote sensing and hydrologic modeling-based datasets, finding that there are about 145,000 and 655,000 ha of land suitable for solar irrigation in Ségou and Sikasso, respectively. During the wet season, surface water yield can support vegetable crops with low water requirements (~300-550 mm/season) in Ségou and Sikasso. Groundwater availability data shows that Ségou has more groundwater than Sikasso, but annual groundwater recharge rates are higher in Sikasso than in Ségou. The study indicates that supplemental irrigation from groundwater is essential to avoid crop failures. Groundwater resources are available to provide supplemental irrigation and meet most of the crop water requirements during the dry season for an area of about 270,000 ha in Sikasso and about 80,000 ha in Ségou. However, any large-scale investment in solar irrigation in the two districts would require local verification of current water availability and use as well as guidelines water management for smallholder farmers.

Sub-Activity 2.4.4. Seed system and potential for irrigated (vegetable) seed production assessment

WorldVeg determined that most vegetable seed companies and cooperatives produce vegetable seed during the rainy season because they lack access to irrigation to produce seed during the dry season, but seed production would be more ideal for vegetables in the dry season. Vegetable seed producers face several additional challenges. WorldVeg strengthened the technical capacity of local vegetable seed companies/cooperatives, including on aspects of irrigation management and more effective business operations. The IDSS team are undertaking a suitability analysis of vegetable production in Mali, to follow on the WorldVeg market analysis. The vegetable types considered in the study are shallot, onion, okra, chilli pepper, tomato, squash, eggplant, cucumber, cabbage and lettuce, based on their high economic importance in Mali (Dembélé et al., 2021).

Activity 2.5.: Approaches to catalyze scaling of SSI within market system

Sub-Activity 2.5.1. Identify scaling pathways within market and food system for irrigation of vegetable & seed

IWMI has developed a data collection tool but was unable to go to the field due to COVID.

Sub-Activity 2.5.2. Identify entry points for the improved diffusion of small scale irrigation

IFPRI implemented two stakeholder workshops for identifying stakeholders in the SSI technology diffusion space as well as their interlinkages (March 2021). The first, national level workshop took place in Bamako with government officials, NGOs, researchers and donors. The second sub-national workshop, held in Sikasso included representatives from the same actor set with a larger number of organizations representing farmers. The national workshop identified 73 different actors and the regional workshop identified 48 actors who are linked to the diffusion of SSI. The results show two almost parallel sets of actor networks, one around the two key government agencies, DNGR (National Directorate of Rural Engineering) and MAEP (the Ministry of Agriculture, Livestock and Fisheries); and the other around a series of farmer associations, such as the Association of Female Market Gardeners and Inter Professions. A working paper based on these results is in preparation. (See Annex 8. Identify entry points for the improved diffusion of small scale irrigation.)

Sub-Activity 2.5.4. Business model and finance/credit modalities for scaling inclusively

ILSSI ME and research partners implemented a competitive private sector RFA and concluded sub-agreements with two companies with varied technologies, distribution approaches, and finance services, being EMICOM (FuturePump distributor) and Ecotech Mali (ENNOS distributor). (See Annex 1. Private sector partnerships: Progress toward milestones and key lessons.)

Objective 3: Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production

Activity 3.1: Institutional and policy analysis & strengthening of governance

Sub-Activity 3.1.1. Design and pilot governance studies using different methods

Ethiopia: The field team completed baseline and endline data collection; analysis of the endline is on-going. Initial results were presented in two conferences (See *Conference papers and posters; Presentations*).

Ghana: Scoping study for site selection in the Feed the Future Zones of Influence was completed, based on: strong competition for water resources, declining groundwater levels, irrigators drawing on the same aquifer, and confined aquifer areas so that interventions by farmers can make a difference. IFPRI is identifying sites, contracting implementers, and applying for IRB approval to proceed with fieldwork.

Women's group engages in experiential games in Ethiopia. Photo credit, IFPRI.

Sub-Activity 3.1.3. Conduct cost-benefit analysis of irrigated fodder production

ILRI collected data for cost-benefit analysis of irrigated fodder production through a farm level accounting of all inputs, expenditures and outputs associated with: 1) irrigated fodder production and use, 2) irrigated vegetable production, and 3) irrigated Khat production. A total of 30 households who have been using SSI for more than three years were selected and used as respondents. The data allowed comparative analysis of the costs and benefits of the three alternative options. Sale of fodder as a cash crop has been common in the SNNPR, whereas use of cultivated fodder for own livestock has been common in the Amhara region. In both scenarios, the preliminary analysis indicates the competitiveness of irrigated fodder to generate similar farm income to the compared crops. While COVID delayed data collection, the research report is expected in FY2022.

Activity 3.2: Analysis of approaches for equity (along value chains), focused on women and youth

Sub-Activity. 3.2.2. Gender and inclusivity

3.2.2a. Understanding the linkages between SSI and women's empowerment

- IFPRI paper on local perceptions of empowerment in the Upper East Region of Ghana and how a SSI intervention targeted to men and women farmers influences pathways to women's empowerment. The results show that many women face serious constraints to participating in and benefitting from SSI, including difficulties accessing land and water and gender norms that limit women's ability to control farm assets. Despite these constraints, many women do benefit from participating in irrigated farming activities leading to an increase in their agency and well-being achievements. For some women, these benefits are indirect—they allocate their time to more preferred activities when the household gains access to modern irrigation technology.
- IFPRI paper on the potential for SSI technologies to increase women's empowerment by evaluating the impacts of an intervention that distributed motor pumps to small groups of

farmers in Northern Ghana. The findings suggest some potential for SSI technologies to provide a pathway for women's empowerment, however, there are also potential negative impacts, including among households that did not benefit from the intervention. The results highlight the need to pair interventions that distribute agricultural technologies with investments in infrastructure that increase access to water for irrigation as well as other interventions that ensure that women can reap the benefits.

3.2.2b. Gender sensitive business models and scaling, aligned with private partners

- Target women for client acquisition: IWMI carried out gender segmentation in Rensys's geographical distribution areas based on livelihood capitals and irrigation investments. Initial findings highlight four gender segments for SSI investment as inputs for the inclusive business model to be co-developed with Rensys: Women investors who rent land from farmers and invest in irrigation; Better off women from households that own land size >= 0.5ha, and/or who have alternate source of income to invest; Household head women investing into irrigation; Resource poor women from households with land size <=0.25ha or who are landless and mainly use surface (lake, river) for irrigation through diversion and sometimes by renting pump.
- Credit access: IWMI recommended changes to PEG Africa's credit scorecard for additional criteria to address gender and social inclusion. Specifically, the revised credit scorecard included 1) financial potential on and off-farmer, 2) social capital and information access. IWMI also co-developed gender sensitive credit assessment scorecard and credit review process with Rensys.

Sub-Activity 3.2.3. Gendered irrigated fodder value chain analysis

ILRI has completed the qualitative part of the gender analysis study. The study aims to assess the contributions of irrigated fodder development in women empowerment, household nutrition, and coping with climatic shocks. In addition, a women's dairy cooperative has been supported as part of ILSSI's private sector partnerships to understand scaling.

3.2.4. Analyze drivers of adoption/dis-adoption of irrigated fodder production

ILRI completed analysis on drivers of irrigated fodder production, showing household characteristics of adopter and non-adopter farmers. The study highlighted the types of farm households to target in the short term for accelerated adoption/scaling and the capacity building needs in the medium and long term engagement of smallholders to adopt the new practices.

Adopters and non-adopters showed significant differences in age of household head, education level, irrigated land size, dairying experience, number of lactating cows owned. A binary probit model was employed to determine significant driving factors that influence adoption. Institutional factors such as membership to cooperatives, availability of training, credit services and forage supply were found to positively influence the decision of farmers.

The age of the household head negatively affected the probability of adopting irrigated fodder technologies. As the age of the household increases by a year, the probability of adopting irrigated fodder would decrease by about 3.4%. Yet, as the level of education of the household head increases by one year of school education, the probability of adopting irrigated fodder increases by about 9.3%. As the irrigated land size increases by a unit of area, the probability of adopting irrigated fodder increases by about 77%, suggesting the strong link between irrigation experience and adoption of irrigated fodder cultivation. Ownership of crossbred cows and size of lactating cows were found to strongly and positively influence the adoption rate.

Activity 3.3: Assess approaches for more nutrition- and health-sensitive SSI

Sub-Activity 3.3.1: Assessment of Multiple Use Systems in Ethiopia, Ghana and Tanzania

IFPRI paper "Seasonal variation in maternal dietary diversity is reduced by SSI practices: a longitudinal study" was accepted by *Maternal and Child Nutrition.* Results showed women from irrigating households had higher Women's Dietary Diversity Scores and were more likely to meet the Minimum Dietary Diversity for Women in the February-April and July-August seasons, than women from non-irrigating households. Consequently, the Government of Ethiopia's plan to expand irrigation projects in the country could improve nutrition if oriented towards the production of nutrient-dense foods.

Sub-Activity 3.3.1a. Assessment of WASH-irrigation interlinkages

A paper on irrigation-WASH linkages centered on Ethiopia using data from 439 households was finalized for submission to a Special Issue of *Agricultural Water Management*. While the study provides tentative evidence that irrigators have better water access and sanitation, there is stronger evidence that water source is important for hygiene practices. Key findings include: 29-35% of irrigators use the same water source for domestic and irrigation purposes, practicing multiple water use. Those that use ground water for irrigation are more likely to use the same water source for domestic water compared to those that use surface water for irrigation, and both groups are more likely to utilize the same water source for domestic and irrigation purposes in the dry season. Non-irrigators are more likely than any other group to have insufficient water for domestic purposes; more than 90% of households that irrigate report sufficient water for domestic purposes. Evidence shows that households that rely on surface water for both their domestic and irrigation needs have worse hand washing practices. They report fewer situations where hand washing is practiced, and they are less likely to wash their hands before handing food. Consistent with this the study indicates that SW households are less likely to have a hand washing station at all, and if they do have one, they are less likely to have soap available at this station.

Sub-Activity 3.3.2. Examining the impact of production systems that include improved irrigated fodder on livestock productivity (milk and meat production), household nutrition and economic improvement

Economic and nutritional impacts of irrigated fodder development were analyzed using the FARMSIM model. Results show annual average profit under alternative scenarios (irrigation) is almost twice that of the baseline scenario (rainfed alone). However, it also highlighted the risk for farmers associated with high production costs and water lifting (e. . solar pump) for SSI. Nutrition analysis for irrigators shows available protein increases by 12%, fat by 24%, calcium by 73%, and vitamin A by 17%. Analysis on the impacts of these alternative scenarios for women's empowerment and gender equity is underway.

Objective 5: Assessment of watershed and SSI interventions on nutrition and resilience under PSNP in Ethiopia

Activity 5.1: Assessment of the implementation of the PSNP watershed rehabilitation approach; identification of limitations to the approach and role of upstream watershed rehabilitation on irrigation sustainability

Remote sensing analysis and biophysical modeling were conducted to evaluate the impacts of watershed conservation and irrigation interventions under PSNP. Results showed that implementation of interventions improved greenness in intervention areas in dry season, including in years dominated by drought. Likewise, a revised universal soil loss (RUSLE) analysis using land use data before (2006) and after (2019) watershed interventions showed that soil erosion was lower after the implementation of the interventions. Biophysical modeling using the SWAT model is underway to further understand the impacts of watershed interventions on soil erosion, surface runoff generation, groundwater recharge and soil moisture. (See Annex 9. .)

While information was gathered from the implementers (CRS, WV &FH) and focus groups with beneficiaries completed, transcribed, and coded, IFPRI had to drop all Tigray sites and sites that are close to Tigray due to unrest spilling over into adjacent regions where much of the USAID BHA activities are taking place. This required rapid changes in the final site selection. Currently, IFPRI is working on the report and interesting impacts on nutrition and gender equality are emerging.

Activity 5.2: Qualitative assessment of watershed rehabilitation and small scale irrigation

Qualitative data were collected from project beneficiaries in Amhara and Oromia regions and in-depth information on program implementation was collected from experts. Based on consultations with the national experts, the overall planning, design, targeting, and implementations mechanism and challenges of the PSNP public works investment were captured, and a first report produced. The program supports project beneficiaries to be food self-sufficient, and the rehabilitation works play a significant role in restoring natural resources. Besides, the irrigation investment benefits the local community through increased food harvest though the structure is prone to quality issues.

Activity 5.3: Quantitative assessment of watershed rehabilitation and small scale irrigation investments

IFPRI completed the quantitative study using the Feed the Future (FtF) 2.0 data collected in 2019, which includes 28 of the 39 woredas with BHA works. IFPRI assessed the impacts of the investment on watershed rehabilitation and irrigation practice, food security, and resilience-building. Descriptive and econometric analyses were employed, and a report has been written. Results demonstrate a positive association of BHA investments to improved food security and coping capacity of beneficiaries.

3. Objective 4 - Achieve impact through uptake of ILSSI research results and/or methods

Activity 4.2. Short-Term and Long-Term Training on subject matter

Sub-Activity 4.2.4. Short-term trainings targeted at producers, technical experts, other local and national stakeholders and private sector

The Actual trainees counted far more than the Target, as shown in Table 1. While HICD initially declined with COVID, trainings resumed with safety protocols. WorldVeg and ILRI both provided trainings in irrigated value chains. Private partners also began trainings with distribution companies, public agencies and producers. ILRI partners (sub-sub-awards) with three dairy cooperatives to develop their capacity as forage seed suppliers to the local area; the cooperatives established forage seed multiplication centers, forage seed shops and milk collection centers. A list of trainings by subject and country is in Annex 10. Short term capacity development.

Table 1. Summary of short-term trainees

Short-term Training Module - EG.3.2-1: Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training		
Total trainees	**Target**	**Actual**
Non-disaggregated total trainees	**174**	**2667**

EG.3.2-1 Producers: Number of producers who received USG-supported short-term agricultural sector productivity or food security training	2021 (Current)	
	Target	**Actual**
Male	93	1552
Female	32	595
Disaggregation not available	0	0
Sub-Totals	**125**	**2147**
EG.3.2-1 Government: Number of individuals in government who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	18	54
Female	1	1
Disaggregation not available	0	0
Sub-Totals	**19**	**55**
EG.3.2-1 Private Sector: Number of individuals in private sector firms who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	20	141
Female	10	27
Disaggregation not available	0	0
Sub-Totals	**30**	**168**
EG.3.2-1 Civil Society: Number of individuals in civil society who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	0	4
Female	0	4
Disaggregation not available	0	0
Sub-Totals	**0**	**8**
EG.3.2-1 Other: Number of other individuals who have received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	0	91
Female	0	24
Disaggregation not available	0	0
Sub-Totals	**0**	**115**

Sub-activity 4.2.5. Post-graduate research training/mentoring

ILRI, IFPRI and TAMU all had new or continuing graduate students and post-docs supported by ILSSI, as listed in Table 2. IWMI selected three MSc graduate student candidates with Bahir Dar University to begin in the next fiscal year.

Table 2. Long Term Trainees

M/F	University	Degree	Major	Program End Date	Home Country
Female	University of Hohenheim	Ph.D.	Agricultrual Economics	Mar/2022	United States
Male	Bahir Dar University	Ph.D.	Water resources engineering and management	Feb/2023	Ethiopia
Male	Bahir Dar University	Master's	Agricultural Economics	Nov/2021	Ethiopia
Female	Texas A & M	Master's	Geography	May 2022	U.S.
Male	Texas A & M	PhD	Water Program (inter-disciplinary)	May 2023	U.S.

Sub-Activity 4.2.7. Innovation Scholarships and Internships

Ghana: IWMI and private sector partners are implementing innovation scholarships and internships. Interns are based at/work with private sector partners, and IWMI coordinates and facilitates between all interns for interactive, safe learning. Four interns were recruited to work with partners in Ghana.

Ethiopia: IWMI sub-sub-awarded to Bahir Dar Institute of Technology (BiT)/Bahir Dar University for innovation scholarships and internships. This has developed BDU capacity to guide students to co-develop solutions with private sector companies to address their needs/challenges. An Agri-hackathon and Innovation Grant were organized to address challenges of SSI technology suppliers. The Agri Hackathon 2021 included semi-virtual trainings for students on human centered design, a field tour, mentorship, and a pitching competition. Selected students are working with Renys Engineering on solutions and prototypes of after sales support system, digitalization of client assessment tool and smart irrigation watering system. In addition, 3 MSc students were selected to study: 1) predicting shallow groundwater levels using machine learning, 2) comparative economic analysis of solar and diesel pumps in Dangila district, and 3) ex-ante adoption impact evaluation of solar pumps.

INSTALLING DEMONSTRATION AND TRAINING SITE FOR THE SF2 SOLAR PUMP, MALI (PHOTO CREDIT: EMICOM)

Activity 4.3. Engage with stakeholders and other potential end users of research

Sub-activity 4.3.2.-4.3.3. Sub-national and national events, platforms/dialogues, and other convenings

In addition to the Multi-Stakeholder Dialogue Platforms in Ethiopia, Ghana and Mali (See Sub-activity 1.2.7), IWMI also participated in 'Duty Free Exemption Policy for Solar Water Pumps', Ethiopia. (10 December 2020) with numerous public agencies, donors, and private sector actors involved in solar pump supply. ILRI organized field visit days for multi-sector actors, including ATA, to visit irrigated fodder sites in Ethiopia.

Sub-activity 4.3.4. Regional and global events, platforms/dialogues, and other convenings

ILSSI targeted events at global, regional and national scales, to share research and engage potential end users. ILSSI research informed multiple tracks of the UN Food Systems Summit, content of engagement with the UN systems, World Bank, and African Union around farmer led irrigation, featured in a side-session at the World Food Prize and co-convened multiple sessions at both the Water for Food Conference and the Stockholm World Water Week. (See Annex 11, *Outreach/Engagement*.)

Activity 4.4. Outreach and communications

Sub-Activity 4.4.3-4.4.5. Outreach knowledge products and communications

- **Website**: 9,257 page views have been recorded for the ILSSI website during this period.
- **Social media presence**: On social media, tweets from the ILSSI profile gained more than 67,000 impressions, and Facebook posts reached more than 3,040 readers during this period.
- **Newsletter**: Potential of Irrigated Fodder Production [December 2020] (open rate 47.8%, click rate 14.0%); World Water Day: Working with farmers to make the most small scale irrigation [March 2021] (open rate 42.1%, click rate 12.7%); Micro-, Small and Medium-sized Enterprises Day: Expanding small scale irrigation with double wins for farmers and businesses [June 2021] (open rate 48.5%, click rate 14.5%). The number of newsletter subscribers grew by 31 during the past 12 months with a current total of 212 subscribers.
- **News stories**: 21 news stories were produced and published on the ILSSI website, including on how irrigating fodder crops improves nutrition for animals and people, how ILSSI and partners

boost small scale irrigation in Mali by training vegetable seed producers, and how groundwater games break new ground in Ethiopia. The program has also been featured elsewhere, including by the Africa Energy Portal, Agrilinks.org, Farmers Review Africa, LEAP4FNSSA and local newspapers in Mali.

- **Briefs**: 6 (See Annex 11, *Briefs*.)
- **Webinars**: 7 (See Annex 11, *Outreach/Engagement*.)

Sub-Activity 4.4.7. Scientific conferences and invited scientific presentations

ILSSI researchers participated in few in-person conferences and a small number of virtual conferences. ILSSI research was presented at over 12 conferences (See Annex 11, *Conference papers and posters; Presentations*,)

Sub-Activity 4.4.8. Publications and data

ILSSI continued to see strong collaboration across research partner institutions on both publications and outreach materials. The figures for each type of publication are summarized in Table 3 below, while the full list of publications with links to web access can be found in Annex 11. Data and publications.

In addition, ILSSI also established a repository of all publications supported by ILSSI in the TAMU library through Oaktrust, to ensure that there is continued access to reports and project-specific technical papers, as well as links to journal publications after ILSSI closes.

Table 3. ILSSI Publications (October 1, 2020 – September 30, 2021)

Category of publication and/or knowledge product	Total Number (all partners)
Peer-reviewed publication	21
Discussion/Working paper	9
Briefs	6
Technical report	1
Conference paper, poster, or presentation	12
Outreach and social media (e.g., blogs)	27
Capacity development material or product	4
Submitted and under review, and/or accepted with revisions	12

4. Technology transfer and scaling partnerships

ILSSI research findings and products were shared through various platforms and events, as well as two donor guidebooks on farmer led and smallholder irrigation. A list of research by phase is in Annex 12. Innovation Transfer and Scaling Partnerships.

In addition, success stories can be found in Annex 13. Success Stories.

Application and/or transfer of analytical methods developed under ILSSI

- ILSSI method on scaling analysis has been included in the World Bank farmer led irrigation guide.
- IWMI and GIZ Scaling Task Force included the adaptive scaling approach for the system transformation in joint publication.
- Research scope to catalyze scaling of SSI/FLI has been expanded by IWMI to new regions under other funding, in Ethiopia, Ghana, Mali and Zambia.
- IDSS tools are being used in the new USAID Mali Mission project to support sustainability of irrigation interventions (Sene Yiriwa).

Use of ILSSI research for scaling irrigation solutions

- Multiple companies and projects, including implementation projects supported by USAID, are using the interactive solar irrigation suitability maps. In addition to solar pump equipment partners of ILSSI (PEG Africa and Rensys), in northern Nigeria, a USD 700 million investment by the World Bank will use the solar suitability maps.
- USAID Mali Mission Sene Yiriwa project is integrating Water Accounting results into planning.
- The dairy cooperative members in the Robit Bata areas (Amhara) increased by about four times over the last 3 years with 203 current members. Spontaneous adoption of irrigated fodder production through farmer to farmer sharing of planting materials have been observed. A total of 102 new farmers, 29% of whom are female headed households, established irrigated fodder on more than 1.3 hectare of land. This is strengthened by the work with cooperatives to multiply forage seeds and planting materials and provide services to the communities. The new forage options that are being demonstrated and evaluated with active engagement of farmers and extension officers have helped to widen the exposure of farmers on alternative materials from which to choose and adopt. Engagement with public agencies had sparked attention and discussion around replication in more areas, but this has stopped with the rising conflict.

Use of ILSSI research to influence policy, investments, and practice

- IFPRI developed a policy brief for UNFSS (United Nations Food Systems Summit) Scientific Support Group on water-food system, "Water for Food Systems and Nutrition". ILSSI research provided the underlying work. See: Water for Food Systems and Nutrition.
- Multi-stakeholder dialogue platform and process in Ethiopia now includes engagement of 2030 WRG, which will expand the reach, visibility and impact, after ILSSI project closure.
- ILSSI researchers at IFPRI, IWMI and TAMU participate in the Global Framework on Water Scarcity in Agriculture (WASAG) Working Group on Water & Nutrition, which includes global actors, such as the U.N. FAO.
- ILSSI contributed to guides targeted at program and project designers, including the World Bank Farmer Led Irrigation guide and forthcoming IFAD and IFC book on smallholder irrigation.

5. Issues, Concerns, and Lessons from the reporting period

5.1. Project Management Issues, Concerns and Lessons

COVID-19 required additoinal approvals for travel and fieldwork and IRB reviews, while fewer people participated effectively in virtual Multistakeholder Platforms. Though restrictions on fieldwork eased, it increased the cost of operation (purchase of masks for all field participants, sanitization, smaller but more groups for engagement, smaller but more groups using transportation, etc). Private partners experienced delays as they obtained approvals to operate as essential services. In addition, the global supply chain slow down and increased shipping prices, as well as the chip shortage, delayed delivery of pumps and in some cases required design changes (e.g. computer chips).

The irrigated fodder partnerships moved slower than anticipated; dairy and producer cooperatives in Ethiopia are unfamiliar with performance-based agreements so sub-sub awards required more time and resources to manage for site level researchers. District officials had to facilitate resolutions of issues with the cooperative in Robit Bata kebele and provision of access to land resources.

Finally, the security risks in Tigray created problems for the BHA buy-in, as well as private partner. The increasing risk is anticipated to seriously and negatively impact research, partnerships, and public events and engagement. A revised workplan and budget may become necessary in FY2022.

5.2. Research-related issues, concerns and lessons

Covid-19 related income shocks dramatically worsened the food and nutrition insecurity in the project countries, while climate change impacts are increasingly felt. As such the focus of ILSSI on governance, resilience and broader uptake of SSI for multiple uses, has increased. Notably, as the project enters the last 18 months, we will extend analysis related to climate adaptation, mitigation and water quality.

ILSSI research has consistently shown the value of SSI to adaptation, resilience and nutrition, as well as profitability for farmers and willingness to invest in new markets by equipment suppliers. However, national and regional policies and regulations block efforts at scaling. For example, unmet and rising demand for quality vegetable seed in Mali could be addressed through SSI, but restrictive seed laws and regulations (e.g. such as mandatory seed certification) disincentivize farmer investment in production. In addition, lack of monitoring and regulation of groundwater development in Ghana has created the context for farmers to be cheated by borehole drillers and irrigation input suppliers, while setting up future water scarcity. ILSSI research has analyzed policies and the negative impacts on both farmers and natural resources, but effective policy engagement and broader capacity development is needed beyond ILSSI current scope.

6. Future work

Objective 1. Identify and Test Approaches to Sustainably Scale SSI through Reducing Constraints and Strengthening Opportunities for Access

- Continue scaling partnerships with private sector partners
- Continue scaling pathways analysis
- Multistakeholder dialogue platform meetings in Ethiopia, Ghana and Mali (virtual and in-person); connect the grassroots scaling ecosystems into the national dialogues
- Complete analysis on farmer-led irrigation policy spread and change
- Manage partnerships with dairy cooperatives; support to be operational in forage seed market

Objective 2. Identify and test approaches to scale SSI to be sustainable and support resilience

- Analysis on affect of sub-optimal uses of complementary inputs on returns from irrigation
- Risk assessment: performance of solar PV SSI under variable and changing climate conditions
- Complete analysis on potential of SSI and improved soil management practices on cocoa production, income and nutrition (Ghana)
- Assess future climatic risk on water availability and crop production; Identify cropping systems (legume crops, fodder, etc.) that provide best productivity under different climatic scenarios
- Evaluate the performance of different forage varieties under irrigation (Ethiopia)
- Identify pathways from water access/management to improved water/food security, sustainable resilience (Mali)
- Identify scaling pathways within market and food system for irrigation of vegetable & seed (Mali)
- Facilitate linkages between vegetable and vegetable seed producers with private sector; Analyze current practices, adoption process, constraints and equitability of irrigated production (Mali)
- Develop strategy for scaling irrigated vegetable production (Mali)
- Guidance on implementing nutrition-sensitive irrigation (Mali)

Objective 3. Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production

- Continued analysis on the linkages between SSI and WASH, and multiple uses
- Continued implementation and analysis of community-level water governance approaches
- Complete analysis on irrigated fodder, empowerment, household nutrition, climate resilience
- Continue analysis and redesign of finance tools and instruments for inclusivity

Objective 4. Achieve impact through uptake of ILSSI research results and methods

<u>Short-term and long-term trainings</u>

- Dairy and irrigated fodder partner cooperatives
- Vegetable seed cooperatives
- Producer and public agency trainings on solar pump (PEG Africa, Rensys, EMICOM, Ecotech)
- IDSS trainings (Ghana, Ivory Coast, Mali)
- Mentor/support graduate students and field assistants; Continue Innovation Grants, Internships

<u>Outreach</u>

- Series of targeted meetings on SSI, farmer led irrigation and multiple use services
- African Water Week; Stockholm World Water Week; Water for Food Conference

<u>Knowledge products and publications</u>

- Numerous papers and reports published, submitted and/or under review
- Quarterly newsletters continue publication on schedule
- Materials for educating farmers on safe pesticide use by private sector partners and by USAID supported Sene Yiriwa (Mali)
- Briefs: Solar irrigation assessments, sub-national, Ghana and Mali; Groundwater governance; Inclusive finance for irrigation equipment; Gender and inclusive SSI; Irrigation and Nutrition

Objective 5: Assessment of watershed and SSI interventions on nutrition and resilience under PSNP in Ethiopia

- Complete assessments of the benefits of Bureau of Humanitarian Assistance (BHA) investments watershed rehabilitation and irrigation in PSNP woredas of Ethiopia.

Annex 1. Private sector partnerships: Progress toward milestones and key lessons

Rensys Engineering (Ethiopia)

Observations and lessons

While this is a private sector activity with market-based targets, the company's approach centers around public sector engagement. The company has emphasized outreach with agriculture and energy agencies and farmer unions, and used a participatory approach to agree on target market areas and potential clients. Attention has been given to obtaining government permissions and exemptions. The most market-based activity has been establishing the MBirr payment system. The company has been negatively affected by COVID (staff loss and turnover) and conflict in Tigray. The pump supplier (Kenya-based) increased support to the company, though has concerns over the potential risks associated with increased conflict.

Milestones completed in FY21:

- Milestone 1. Strategic business and operations plan
- Milestone 2. Initial market study conducted; marketing strategy and plan developed
- Milestone 3. PayGo and payment platform (MBirr) integrated. Rensys staff trained on use of MBirr and system.
- Milestone 4. Credit algorithm tool developed, tested and ready for use. Developed with Bahir Dar University and IWMI through a Hack-a-Thon and 'innovation interns' placed with Rensys.

Milestones behind schedule:

- **Milestone 5. Distribution/marketing hubs** established in 4 sites(Amhara, SNNP, Oromia).
  Issues: Rensys has had difficulty importing pumps. This is primarily related to shipping bottle necks.
  Measures to address/progress:
  - Rensys changed the shipping route to deliver through Kenya, though this also created delays with the changes to financial documents. Pumps (390) were expected to arrive in October 2021.
  - Ministry of Agriculture approved tax exemptions for the imported solar pumps
  - Pump supplier (SunCulture) is supporting set up of distribution network.
  - Rensys is providing demonstrations to government bureaus, extension, and farmer cooperatives
    - *Oromia - Meki, Adami tulu, Mojjo (Under Lume Adama union), Ejere East shoa zone, Ambo, Harari in the east.*
    - *SNNPR - Hawasa (sidama zone), Gamugofa union, Hosaena, Gurage zone*
    - *Amhara - North Shoa - Minjar, Balchi, Berehet,*
- **Milestone 6 – Cold stores [solar powered, off grid] operational**
  Issues: Constraints to forex access and high prices of solar powered cold stores that must be imported.
  Measures to address/progress:
  - Rensys has identified a solar powered cold store to purchase in country in Birr.
  - Rensys led a participatory process with farmer unions to identify a site for placement of cold stores central to irrigation clusters aligned with good environmental practice.
  - Rensys prepared the land request letter to the region investment offices with support letters from key stakeholders (farmers unions, agriculture and energy bureaus).

PEG Africa (Ghana)

Observations and lessons:

Sales figures and pump uses: PEG sold 105 pumps, below the target number of 124, for the period. They are adapting marketing and financial products. PEG has found poultry and livestock farmers as a market, beyond anticipated sales to horticulture producers. In addition, PEG has several clients in cocoa, usually multi-cropped with higher value produce; PEG is exploring a business model for cocoa farm rehabilitation with ECOM. Nearly all clients allow neighbors to use water for domestic purposes.

Marketing approaches: The initial marketing strategy and plan required adjustment to market realities. PEG has added new partnerships, such as with borehole drillers, irrigation pipe and drip tube suppliers. PEG has bundled boreholes with pumps in their asset-based finance package. Partner projects include Agrihouse, Greentech Holland and SNV Hortifresh. They have added and trained more district (local) sales agents with distribution shops acting more as stores and technical support. About 15% of sales are coming through social media platforms. PEG also noted the value of customer service, as farmer 'word of mouth' has been important for added sales.

Asset-based finance and the credit scorecard: The credit scorecard for asset-based finance was developed with support of CGAP, but PEG observed that most smallholders lack the required documentation, so the credit review process and products had to be adjusted. In some cases, PEG rejected applications and instructed farmers on documentation needed, then farmers reapplied successfully 3-6 months later. Also, scorecard criteria have been adapted to include information more favorable to women farmers, which is now being tested in comparison to the standard criteria alone.

Only two farmers defaulted, both subsidized through SNV's Hortifresh project. Farmers failed to make any payments after the SNV downpayment. This raises questions on modalities for 'subsidized' support.

Business case for smallholders: PEG engaged an agronomist to support farm practices. They also established a WhatsApp group PEG Farmers' Class to respond to questions and share information. PEG identified potential produce off-takers, but few farmers requested this support. Rather, PEG found higher demand to link clients to reliable input suppliers.

Many of the farmers are replacing grid pumps and/or petrol and diesel pumps (about 55%) with significant decline in costs through use of solar. Farmers that had previously used manual labor for fetching water and on-field irrigating note savings in labor costs. Several clients interviewed intend to expand the areas under vegetable and fruit production.

Milestones completed in FY21:

- Milestone 3. Marketing strategy and plan [including financial products to be offered]
- Milestone 4. Credit algorithm tool/ scorecard developed, tested and ready for use.
- Milestone 6. Set-up of supply chain and distribution network (Eastern-Volta, Western-Ashanti and BA regions)
- Milestone 7. Set-up of supply chain and distribution network (Northern regions)
- Milestone 8. Sales and technical training of field staff (all regions)
- Milestone 9. Impact assessment and monitoring (initial/baseline)
- Milestone 10. Sales records (pumps)

Issues:

- Borehole cost and professional borehole services is a major constraint for many of the interested farmers. At the same time, PEG often determines the pump/panel based on the borehole. Many of the boreholes are deep, and require a larger and more expensive pump, but it is unclear if the boreholes are at the appropriate depth, because many borehole services are untrained, the industry unregulated and anecdotal evidence suggests farmers are being cheated by drillers.

- Most pumps are used for multiple purposes, including providing water for domestic uses for neighboring households, which makes it difficult to assess how much water is being used for agriculture and therefore, if farmers are using 'too much' water.
- While PEG did not achieve the targeted sales figure, and has not expanded sales in the northern regions as intended, they have adapted their marketing and financial products to increase sales.
- As PEG has better understood the market, they share concerns about the feasibility of reaching the very bottom of the pyramid of farmers.

Ecotech Mali (ETM)

Observations and lessons:

ETM's approach that emphasizes social embeddedness: in-depth farmer trainings (financial management and agronomy), engagement with community leaders, and sales and post-sales support through village based agents. ETM has prepared videos and written materials in local languages on solar irrigated agronomy.

Finance: ETM's credit terms are lease-to-own basis. ETM's financial management capacity building strategy and tools support farmer business and help ensure reliable payments. Financial capacity building, tools and documentation are expected to enable farmers to access finance for other agricultural inputs. A financial self-assessment tool has also been developed for cooperatives interested in solar pumps.

Issues:

Two primary concerns of ETM are the pump cost and cost of credit for the poorest farmers; ETM is adjusting their repayment period to 2 years to reduce the downpayment and extend balance payments, and identifying other credit sources for complementary inputs for farmers. ETM's team has approached the BDM Bank, Soro Yiriwaso Microfinance and KAFO Jiginew, who are willing to introduce solar pumps to their clients as well as share some information about their clients.

Milestones completed in FY21:

- **Milestone** 1. Social marketing strategy and plan completed
- **Milestone2.** Strategy and agreement in place with financial institution; Credit assessment or scorecard tool for potential clients completed.

EMICOM

Observations and lessons:

EMICOM achieved the first four milestones and sold 134 SF2 FuturePump irrigation kits sold to 24 clients. Their market segmentation targets crop and horticulture, livestock, poultry and fish farmers. They made demonstration visits to 90 villages (Koulikoro, Kayes, Segou, Sikasso, Koutiala and Bougouni) providing awareness and basic training on solar pumps to1492 people, 36% of whom were women (539). EMICOM's marketing model is based on an extensive network of distributors ; 8 sub-distribution agreements have been concluded with 5 pending (including 1 woman entrepreneur). EMICOM has also prepared modules and training materials on the maintenance of SF2 kits and provided training to distributors. They have continued to progress on their agreement with BNDA for preferential finance for farmers, while also setting up a partnership contract with ANGAZA for the payment of kits in tranches and with Orange Finances Mobile Mali. Additional partners include the 2Scale incubator program, Support Center for Microfinance and Development (CAMIDE), the Benso Jamanun Association, and a partnership discussion with the National Directorate of Agriculture (DNA) to involve the Regional Directorates of Agriculture in the identification of the villages most favorable to the extension of the solar pump.

Milestones completed in FY21:

- **Milestone 1.** Marketing and promotion: Campaign strategy and plan completed (market segments and target groups identified)
- **Milestone 2.** Distribution network and demonstration. Operationalization of the assembly and maintenance team, e.g. trainings
- **Milestone 3.** Distribution network and demonstration; Demonstration fields prepared and active.
- **Milestone** 4. Finance partnership and PAYGO digital platform payment system established.

Issues:

EMICOM noted that they have no sold pumps to any women or youth, and plan to look at potential partnerships that might help them reach those market segments. They also sold most of the 124 pumps for cash, so the lease-to-own system is yet to be fully developed and tested.

Annex 2. Assessing the potential to scale fodder production in Ethiopia

The Ethiopian economy largely depends on rainfed agriculture (Yami and Sileshi, 2001). Livestock is an integral part of the agricultural system accounting ~40% of the economy and employing over 30% of the agricultural labor force (Declaration, 1996; Asresie and Zemedu, 2015). Although Ethiopia has substantial livestock population (CSA, 2017), shortage of feed, seasonality, feed quality and lack of access to basic veterinary services hampered the sector's productivity (Ahmed et al., 2016; Tonamo, 2016).

Major feed sources for livestock feed in Ethiopia are open grazing on natural pasture, and crop biomass (Mengistu, 2006; Birhan and Adugna, 2014). As the rainfall season recedes, the biomass growth in the open grazing land starts to seize, and available biomass will also be consumed by the livestock. Consequently, livestock keepers relay on crop biomass stock to feed their livestock during the dry season. However, the biomass stock may not be insufficient quantity and quality to meet the feed demand during the dry season (Yami et al., 2013; Dejene et al., 2014). Irrigated fodder is, therefore, considered as an option to produce and supplement the fodder demand during the dry season. ILSSI has been identifying areas that are suitable for fodder production across Ethiopia. During this project reporting period, the IDSS team assessed the potential to produce biomass, water resources availability and irrigation demand to produce livestock feed such as Napier grass (*Pennisetum purpureum*), vetch (*Vicia villosa*), oats (*Avena sativa*), and alfalfa (*Medicago sativa*).

Biomass production

There is substantial potential to produce biomass in Ethiopia using irrigation during the dry season. Although fodder production was assessed using irrigation during the dry seasons, biomass production varies based on the overall biophysical conditions in the climatic year, and location in the country. For example, during the optimal biophysical years, Napier biomass production across Ethiopia ranges between ~9 ton/ha and 78 ton/ha (Figure 1a), while during the suboptimal biophysical years, it could range between <3 ton/ha and 18.28 ton/ha (Figure 1b). The average spatiotemporal Napier, vetch, oats and alfalfa biomass yield were 17.47 ton/ha, 9.95 ton/ha, 3.08 ton/ha and 11.28 ton/ha, respectively.

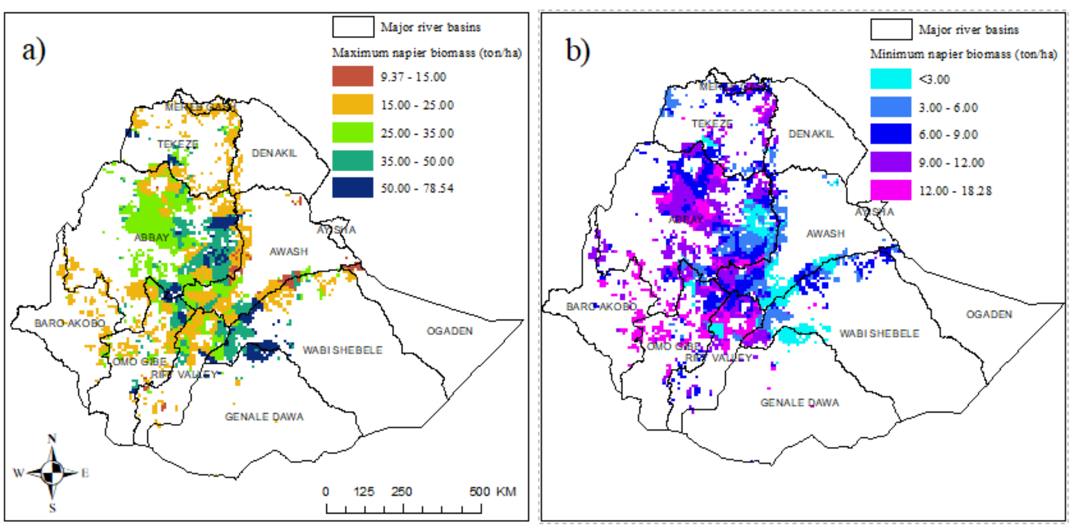

Figure 1. Napier potential biomass production on rainfed agricultural land in Ethiopia: a) during optimal biophysical and b) suboptimal biophysical conditions

Water resources availability and irrigation water requirement to produce fodder

A significant amount of water resources is available to produce fodder in the rainfed agricultural land in Ethiopia. For example, the long-term average annual surface runoff ranges between ~100 mm and 857 mm, and the groundwater recharge also reaches up to 912 mm (Figure 2). The highest amount of water resources is available in the Upper Blue Nile, Baro Akobo and upper part of Omo-Gibe basins. The long-term average spatiotemporal annual water yield (i.e., surface runoff and groundwater contribution to streamflow) was 458.51mm. The irrigation water requirement to produce fodder was far lower than the available water resources across the country. The long-term average spatiotemporal irrigation requirement to produce Napier, vetch, oats and alfalfa were 96 mm, 143.66 mm, 120.44 mm and 101.6 mm, respectively.

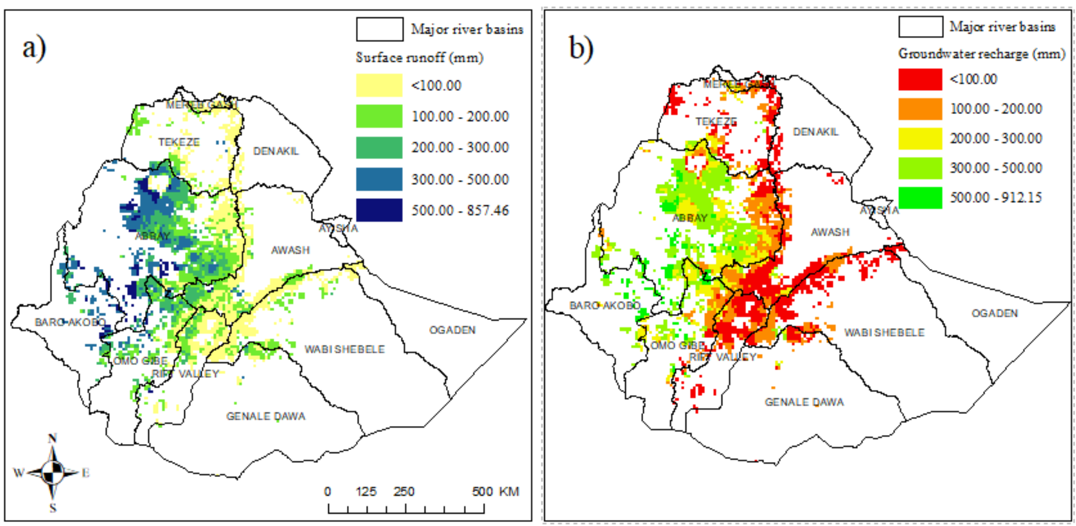

Figure 2. Long-term average annual water resources in the rainfed agricultural land: a) generated surface runoff (mm), and b) groundwater recharge (mm).

Annex 3. Suitability Analysis for Cocoa Production

Majority (~70%) of the world's cocoa (*Thebroma cacao*) is produced in West Africa (Aboah et al., 2019). Ghana and Cote d'Ivoire contribute the lion's share of the world's cocoa production; of which Ghana's share is about 20% of the world's cocoa production (ICCO, 2019). The cocoa industry forms an integral part of Ghana's economy due to its production and export benefits as well as direct job creation (Asamoah and Owusu-Ansah, 2017). Despite cocoa's socio-economic significance, its production in Ghana has been severely fluctuating (COCOBOD, 2016) due to pest and disease outbreaks, inadequate access to finance to farmers, depletion of soil nutrients, and climate change and variability (Laderach et al. 2013; Kumi and Daymond 2015; Ali et al., 2018). As a result several studies (e.g., Laderach et al., 2011, Laderach et al., 2013 and Schroth et al., 2016) indicated that land suitability for cocoa production may decline in large parts of the West Africa. Therefore, the IDSS team assessed potential land suitability for cocoa production in Ghana using GIS-based Multi-Criteria Evaluation (MCE) in this annual reporting period.

Methodology

Important biophysical and socio-economic factors that affect land suitability to cocoa production were selected based on literature and consultation with experts. The biophysical factors were climate (rainfall and potential evaporation), soil, land use, and slope (Table 1), while the socio-economic factor was access to the market, which was represented by proximity to paved roads.

Classification of the suitability factors

Factors for the suitability analysis were classified according to the FAO classification framework (FAO 1976; FAO 1985; FAO, 1989). The suitability levels were defined based on the growth requirements for cocoa, and socio-economic considerations (e.g., transportation of the produce and agricultural inputs to and from the market) (Djaenuddin et al., 2003; Widiatmaka, 2007; Ecocrop, 2010; Kappo et al., 2014, Girma et al., 2020: Table 2).

Table 1. Suitability classes for the biophysical factors to produce cocoa (Djaenuddin et al., 2003; Widiatmaka, 2007; Ecocrop, 2010; Kappo et al., 2014).

	Suitability class			
Factor	**Highly suitable**	**Moderately suitable**	**Marginally suitable**	**Not suitable**
Landuse	Forest	Cropland	Grass, Shrub	Water, Wetland, Built area
Soil texture	Fine, slightly fine	Medium	Slightly coarse	Coarse
pH	5.5 -7.5	4.0 - 5.5 & 7.5-8.0	-	<4.0 > 8.0
Depth (cm)	≥150	75-150	50 -75	<50
Slope (%)	<4	4.0-8.0	8.0-16.0	≥16
Rainfall	1500-2500	2500 - 3000	1250-1500 & 3000 - 4000	< 1250 & > 4000
Temperature	25-28	20-25 & 28-32	32-35	< 20 & > 35

Land suitability analysis using Analytical Hierarchy Process

The weights of the factors were generated using Analytical Hierarchy Process (AHP) which is developed by Saaty (Saaty, 1977). AHP uses a pairwise comparison matrix to determine the relative importance (weights) among pairs of factors that affect growth rates and yield of cocoa based on a 9-point scale measurement (Saaty (1977). Experts in cocoa production completed the pairwise comparison survey for the seven selected factors/criteria through a web-based AHP priority calculator (AHP calculator - AHP-OS (bpmsg.com)). The final weights of the factors were determined using an arithmetic mean of resulting individual priorities from the experts (Forman and Peniwati, 1998). Weighted Overlay function in ArcGIS was used to produce the preliminary suitability map for cocoa production. The final land suitability map was produced by excluding constraint areas such as built-up areas, forest and game reserves from the preliminary suitability map.

Results of cocoa land suitability analysis

Results of the pairwise comparison analysis indicated that soil depth (34%) was the most important factor determining land suitability for cocoa production followed by rainfall deficit (23%) and soil texture (18%) (Figure 3). Proximity to road was the least important factor with a weight of 3%. The Consistency Ratio (CR) values (a measure of inconsistencies in the judgment of decision makers) achieved from the survey ranged between 6.5% and 10%, indicating consistent judgment among experts (Chen et al. 2010; Park et al. 2011).

Preliminary cocoa land suitability analysis showed that 12% of Ghana's land is highly suitable for cocoa cultivation; most of which is located in the southern part of Ghana (Figure 1). The majority of the country (~80%) shows moderate suitability. The final land suitability map shows that 10%, 68% and 7% of the country is highly, moderately and marginally suitable for cocoa cultivation, respectively. (Figure 1).

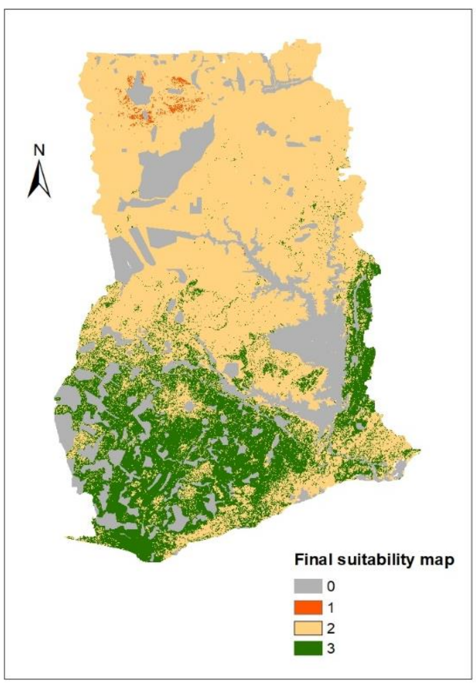

Figure 1. Land suitability for cocoa cultivation in Ghana. The suitability factors 3, 2 and 1 represent most suitable, moderately suitable and low suitabile areas, respectively. 0 represents restricted areas.

Annex 4. Irrigation and water pollution analysis

ILSSI's research showed that small scale irrigation (SSI) improves agricultural production, household income and nutrition. However, since SSI needs to be accompanied by use of agricultural inputs (e.g. fertilizer, pesticides) to improve production, there is a growing concern that use of such inputs may cause freshwater pollution. During this reporting period, the IDSS team assessed the impacts of fertilizer use for dry season irrigated vegetables, lentils, and fodder crops on nutrient loading across Ethiopia.

The study used a gridded 10 km resolution SWAT model that simulates hydrology, crop yield and nutrient loading for the entire Ethiopia. The simulation compared the nutrient loading for baseline model that uses farmers' current practice (Table 1a) and dry season irrigated scenarios of vegetables, lentils and fodder crops (Table 1b). Nutrient loading into the freshwater systems was estimated for the agricultural landscapes within the grids, which include sediment yield, organic nitrogen and phosphorus, and inorganic nitrogen and phosphorus (that are transported through surface runoff, lateral flow, groundwater flow and sorbed into sediments). In this report, the nutrient loading were presented aggregated into sediment yield (ton/ha), total nitrogen (kg N/ha) and total phosphorus (kg P/ha).

Table 1a. Applied fertilizer for major cereal crops cultivated in Ethiopia. Urea is a nitrogen based fertilizer with 46% of mineral nitrogen while DAP has 18% of mineral nitrogen and 20.2% mineral phosphorus.

Major rainfed crops	Urea (kg/ha)	DAP (kg/ha)
Corn	98	98
Millet		70
Teff	53	53
Sorghum	84	84
Wheat	84	84
Potato	75	53

Table 1b. Applied fertilizer for dry season irrigated crops.

Dry season irrigated crops	Urea (kg/ha)	DAP (kg/ha)
Cabbage	170	50
Onion	100	50
Pepper	100	50
Lentils	0	0
Vetch	0	50

Generally, there was a decrease in soil erosion in the irrigated scenarios compared to the baseline condition (Figure 4). For example, the average spatiotemporal annual soil erosion in the irrigated cabbage scenario was 0.98 ton/ha less than in the baseline scenario (t-statistic 4.6912, p-value=2.788e-06, 95% CI [-1.3885,-0.570]). The reduction was in part due to crop cover during the dry season that reduced soil loss due to surface runoff from the rainfall that occur during the dry season.

Total nitrogen in the irrigated cabbage, onion, pepper and vetch scenarios were significantly higher than that of the total nitrogen loading during the baseline scenario (Figure 4). The increase in the total nitrogen was due to the addition of nitrogen fertilizer during the dry season to produce irrigated crops. The increase in total nitrogen loading in the case of vetch fodder crop was also related to contributions from nitrogen fixation. The cultivation of irrigated lentils scenario significantly decreased the total nitrogen loading compared to the baseline scenario (Figure 4). Since lentils is a legume crop that fixes nitrogen, fertilizer was not applied in the irrigated lentils scenario. The decrease in the total nitrogen may be due to consumption of the residual nitrogen from the rainfed cultivation by the dry season irrigated lentils.

Generally, there was a decrease in total phosphorus loading due irrigated cabbage, pepper, lentils and vetch scenario (Figure 1); however, the decrease with the pepper scenario was not statistically significant. The decrease in the total phosphorus could be due to the use of the available soil phosphorus by the dry season irrigated crops. There was a minor (statistically insignificant) increase with the total phosphorus loading due to irrigated onion scenario (Figure 1). The increase in the total phosphorus in irrigated onion scenario could be due to the use of relatively higher phosphorus-based fertilizers during the dry season.

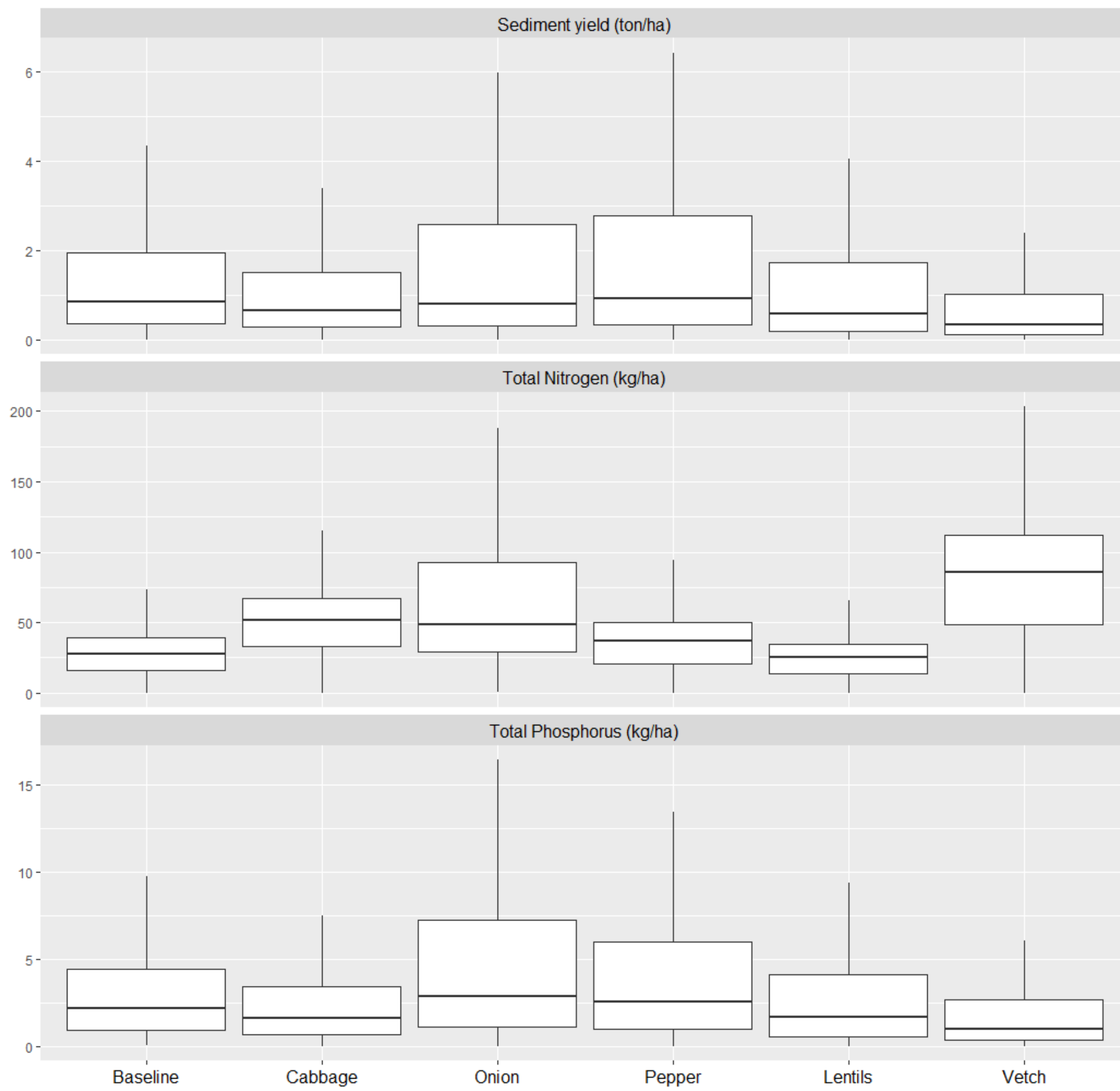

Figure 1. Box plot for long-term spatiotemporal sediment yield, total nitrogen and total phosphorus loading for the baseline and irrigated vegetable, lentils and vetch scenarios.

Annex 5. Assess future climatic risk on water availability and crop production

Climate change data for Ghana was downscaled from multiple GCMs, and climate and weather extremes indices were analyzed (Table 2). The GCMs considered in the analysis include CNRM-CM5 (Centre National de Recherches Météorologiques, which is referred as National Centre for Meteorological Research in English), EC-EARTH (European community Earth-System Model), and MPI-ESM-LR (The Max Planck Institute for Meteorology Earth System Model). The bias in the future climate data was corrected using distribution mapping method, which is available in the CMhyd tool (Rathjens et al., 2016) tool. The bias correction for Ghana was conducted based on 23 observed rainfall and maximum/minimum temperature stations. The observed climate data that was used for the bias correction covers the period 1990 to 2013. The bias corrected climate change data was generated for the period until 2100. The climate and weather extreme analysis was conducted based on the Expert Team for Climate Change Detection Indices (ETCCDI) which facilitates comprehensive analysis of such extremes over the last decade (Karl and Easterling, 1999; Klein Tank et al., 2009; Sillmann et al., 2013). The indices (Table 1) were estimated for the 2020 to 2050 period based on daily rainfall and maximum/minimum temperature data for twelve stations which are located in areas that have better observed data.

Table 1. List of studied climate and weather extreme indices based on the recommendation of Expert Team for Climate Change Detection Indices (ETCCDI)

Index	Index full name	Definition of the index	Units
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm
R1	Number of days above 1 mm	Annual count of days when PRCP>=nn mm, nn is user defined threshold	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
SU25	Summer days	Annual count when TX(daily maximum)>25°C	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX>90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN<10th percentile	Days

Projected climate based on five RCMs and two emission scenarios indicated that the total annual rainfall in Ghana for the period 2021-2050 may decrease compared to historical climate (1984-2013) in most of the studied stations (Figure 5). Ensemble mean of the studied models also showed lower total annual wet-day rainfall compared to the observed rainfall of all of the studied stations. All of the models and emission scenarios showed a lower number of rainfall days (rainfall > 1mm) and very heavy precipitation days (rainfall > 20 mm) in all of the studied stations compared to historical climate. On the other hand, the number of consecutive dry days increased in all of the studied models and stations compared to historical observed climate. While all of the studied models showed a decrease in the projected number of consecutive wet days in most of the studied stations. Generally, the number of summer days were too high in Ghana even in the observed historical climate; however, the projected summer days increased further in all stations due to impacts of climate change. In fact, summer days will be prevalent throughout the year in all of the studied stations. Warm spell duration indicator for the future climate will be higher than the observed climate, and it will have an increasing trend. The projected cold duration indicator will be generally higher compared to the historical climate, but it will have a decreasing trend over the period 2021 to 2050.

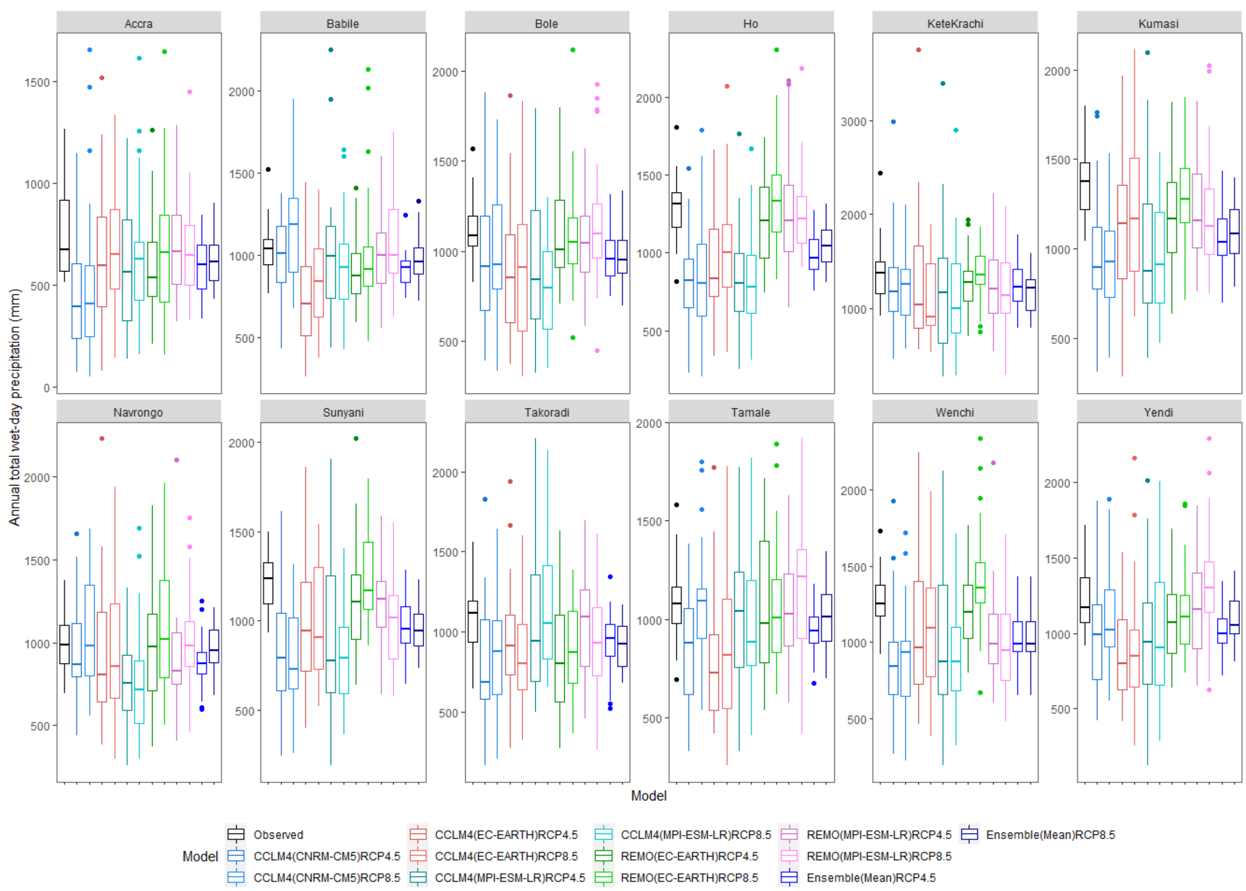

Figure 5. Annual total wet-day rainfall in 12 selected stations in Ghana. A day was considered as wet when the rainfall amount was >1mm. Refer Table 2 for the names of the studied General Circulation Models (GCMs) and Regional Climate Models (RCMs) for the 4.5 and 8.5 Representative Concentration Pathways (RCPs).

The decrease in total annual rainfall, the increase in temperature which leads to an increase in actual evapotranspiration and increase in dry spells (consecutive dry days) suggest that climate change will negatively affect agricultural production in Ghana. This suggests that climate change adaptation strategies should be implemented to reduce the negative externalities of the climate shocks and thereby build social-ecological resilience. Small scale irrigation is one of the strategies that enhances rainfed agricultural production through provisioning of supplementary irrigation and additional production during the dry season. Cultivation of drought resistant crops and crop rotation has been suggested as amongst the best strategies to adapt to the risks of climate change. Land and water management practices may also help to adapt the impacts of climate change by enhancing soil moisture in watershed.

Annex 6. Yield-Index insurance and farmers' resilience: premiums and indemnity schedule

Background

In the face of severe climatic shocks, households in developing countries often reduce assets to smooth or reduce consumption to protect assets (Elabed and Carter, 2014). Both of these strategies have negatives consequences on the economic and nutritional well-being of households and communities. In addition, uninsured households become risk-averse to invest in risky but profitable businesses, rather they engage in traditional technologies that have a low rate of return.

Crop insurance can help to mitigate risks and assure families maintain assets and consumption levels (WB, 2011). Crop yield risk management schemes have been tried in developing countries but with varying degrees of success. Due to a lack of individual producer yield histories, area-wide index insurance policies have been the norm. An area wide index policy can be developed using an index of rainfall or yield information. Index insurance avoids the high costs of conventional insurance by basing payouts on an outside index of factors, such as an area's rainfall or vegetation growth that can be used to accurately estimate yield losses. The main drawback of index insurance is the existence of basis risk (Carter et al., 2014; Clarke, 2016; IFPRI, 2017; Jensen et al., 2018). It is the risk that a farmer might experience a yield loss and receive no insurance payment because the loss is not captured in the established index. This arises from the discrepancy between measured risks at the meteorological station level and the occurrence of weather shocks at the location of the insured farm. A low number of weather stations and existence of microclimates increase the basis risk and make the index insurance cheap and expedient but low-quality product (Clarke, 2011). Although several of the index insurance programs that were piloted in developing countries showed limited success and uptake, the introduction of index insurance in few pilot and experimental studies showed positive results (Carter and de Janvry, 2014; IFPRI, 2017). The basis risk associated with index insurance products can be reduced by designing products that correlate better indemnity schedules with crop losses in the event of a shock (Miranda & Malunga, 2016). Use of dense network of meteorological stations and satellite imagery can help better understand the relationship between weather and crop production, and thereby to design reasonable insurance contracts. However, the lack of historical farm-level yields and losses to establish and understand the crop-weather relations have hampered these efforts. To help close this gap, use of crop growth models based on crop water requirements, which has high potential to predict aggregate yields and its complex relationship with weather, is recommended (Miranda & Malunga, 2016).

ILSSI has been developing an integrated approach combining the Agricultural Policy/Environmental eXtender (APEX) model and farm simulation (FARMSIM) models to generate a yield index and also to assess the economic and nutritional outcomes related to resilience under different insurance schemes. The use of an integrated approach of a crop growth and economic models may 1) reduce the level of the basis risk and improve the yield prediction and insurance index; and 2) provide a better assessment of potential indemnities schedules and household resilience level under different insurance schemes.

Methods

The crop insurance study followed three distinct steps to identify climate risk areas for rainfed production and determine indemnity and premiums of simulated yield-based index insurance (Figure 1). First, the climate risk areas for rainfed cropping systems across the country were identified using rainfall data collected from the Ethiopian National Metrological Services Agency (ENMSA) and Ghana Meteorological Agency (GMA). The daily rainfall data was used to identify major rainfall regimes, which was used to identify rainfed maize growing periods across the country. The growing season rainfall was interpolated with Inverse Distance Weighting (IDW), and classified into multiple rainfall regimes to identify high-risk zones for rainfed production. Rainfall risk areas were identified by evaluating the monthly rainfall distribution and amount over the growing period. The growing season rainfall (of the different rainfall regimes) and maize yield (reported at the zonal level) were evaluated to assess if there is any correlation. Next, the APEX model was calibrated and validated for the observed maize yield and used to simulate long-term crop yield. The long-term simulated crop yield and historical rainfall data of the case study Lemo site were used to determine the threshold index to trigger payouts based on the expected yield losses.

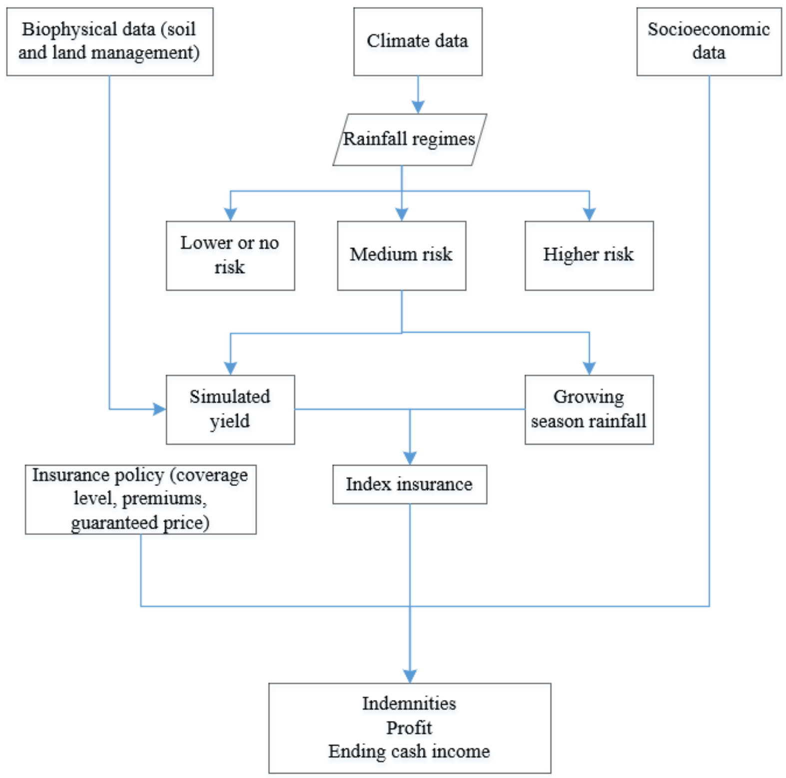

Figure 1. Methodological framework that helps to develop indexed crop insurance system.

Areas susceptible to rainfall variability and risk in Ethiopia and Ghana

Analysis of the rainfed growing season monthly rainfall data (1990-2018) across Ethiopia and Ghana showed three rainfall regimes for both countries (Figure 2 & 3). In Ethiopia, the average rainfed growing season rainfall across Regime I, II, and III was ~980 mm, 445 mm, and 390 mm, respectively. Higher rainfall variability was observed in Regime II with a 34% coefficient of variation, while Regime I has the least rainfall variability with a 20% coefficient of variation. In Ghana, the average growing season rainfall in Regime I, II, and III was ~715 mm, 485 mm, and 416 mm, respectively. Higher rainfall variation was observed in Regime III with 11% coefficient followed by 6.7 in Regime II and 6.4% in Regime III.

In Regime I of Ethiopia and Ghana, ~90% of the area receives more than 700 mm of rainfall throughout the growing season. In this area, the probability of crop failure due to crop water stress is minimum; therefore, investing in rainfall indexed crop insurance may not be feasible. Instead, supplemental irrigation and development of irrigation infrastructures such as rainwater harvesting, small dams, and conservation agriculture might be viable to build climate resilience. In the remaining portion of Regime I (10%) and the majority of Regime II and III, the rainfall amount is well below the crop water requirement of maize and other cereal crops. Therefore, the probability of crop failure due to crop water stress is higher, and there is a need for managing the risk through crop insurance. However, crop insurance may not be practical in extreme risk areas where the payouts will be higher than the collected premium (or may create a premium hike to cover payouts), which is not sustainable for farmers and insurance companies. In areas where the growing season rainfall is less than 300 mm and has higher rainfall variability, it may be better to cultivate drought resistant forage/fodder crops to support the livestock production system (as those areas are most likely pastoral lands).

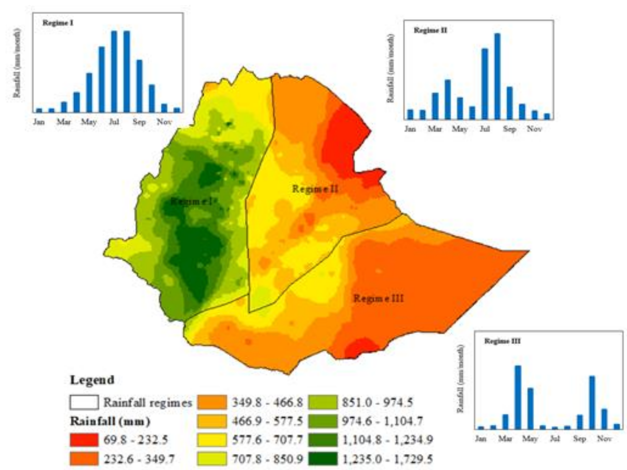

Figure 2. Rainfall regimes in Ethiopia based on long-term (1990-2010) average monthly rainfall and rainfed maize cultivation season average rainfall. Station rainfall was interpolated to spatial rainfall using an Inverse Distance Weighting method.

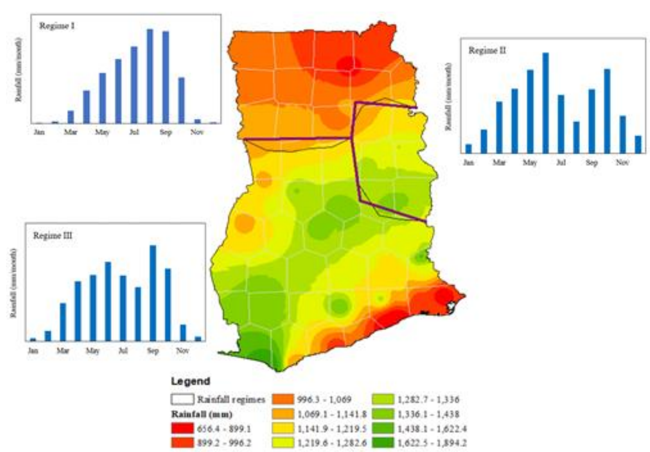

Figure 2. Rainfall regimes in Ghana based on long-term (1990-2010) average monthly rainfall and rainfed maize cultivation season average rainfall. Station rainfall was interpolated to spatial rainfall using an Inverse Distance Weighting method.

Performance of rainfall vs. observed yield at zonal level

The accuracy of rainfall indexed insurance relies on its association with the growing season rainfall. The performance of rainfall indexed insurance was evaluated by comparing the growing season rainfall with the historical maize yield which was obtained from the Ethiopian Central Statistical Agency (CSA) at the zonal level (Figure 3). The degree of correlation of observed maize yield and rainfall amount may illustrate if a rainfall index crop insurance serves as a proxy to yield, or not. Figure 9 shows the coefficient of determination between the growing season rainfall and observed yield at different spatial locations across Ethiopia. In the central part of Regime I, rainfall indicated a strong correlation with maize yield capturing more than 50% of maize yield variability. However, in the majority of the zones in Ethiopia, which are likely vulnerable to rainfall variability, the growing season rainfall did not show a strong correlation with the maize yield suggesting that growing season rainfall is not a good proxy to maize yield. This suggests that simulation-based yield index insurance is a better approach to capture all other factors limiting corn yield.

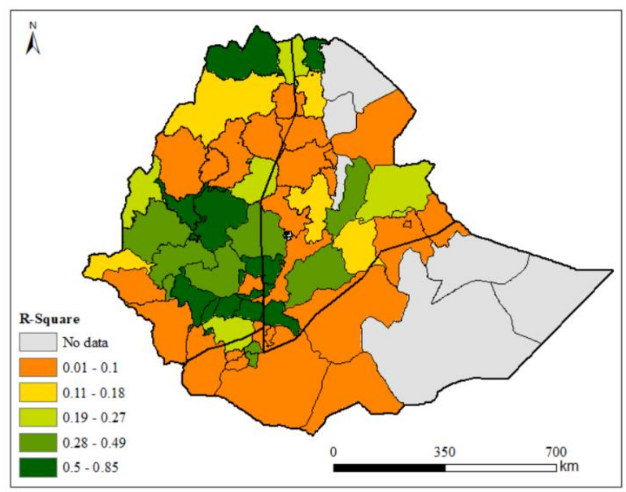

Figure 3. Coefficient of determination between the growing season rainfall and maize yield at the zonal level in Ethiopia (2003 – 2016).

The simulated maize yield using the APEX model for the Lemo site indicated a reasonable performance for both calibration (2000 – 2012) and validation (2013 – 2016) period with R^2 of 0.79 and 0.77, respectively. The PBIAS and the RMSE of the simulated yield were -3% and 0.28 t/ha for calibration and 10% and 0.43 t/ha for the validation periods, respectively. The APEX simulated yield approach captured the historical crop yield very well, reinforcing that simulation-based yield index insurance is a better approach to capture all other factors limiting corn yield. A simulated yield-based crop insurance reduces the basis risk and improve the yield prediction. Therefore, the calibrated and validated APEX model was used to predict the historical maize yield from 1980 to 2019 using local climate data and management practices. The simulated maize yield varies between 1.45 and 2.15 t/ha with an average yield of 1.8 t/ha (1990–2018). The simulated yield distribution indicated that 10.4% of the time, the yield was <1.65 t/ha.

Index insurance development: site selection, yield simulation and indemnity schedule

The insurance development site selection was based on multiple factors, which include the availability of historical climate and crop yield data and vulnerability to the risk of crop failure. Therefore, based on the availability of data, the Lemo watershed/district in Southern Nations Nationalities Region (Ethiopia), and Dimbasinia watershed/district in the Upper East region (Ghana) were selected. Maize growing season rainfall for Lemo area indicated an average rainfall of 600 mm with a standard deviation of 85 mm for the period 1990-2018. While in Dimbasinia, the growing season rainfall varies between 450 and 800 mm with a standard deviation of 90 mm.

The simulated maize yield using the APEX model for Lemo site indicated a good performance for both calibration (2000-2012) and validation (2013-2016) period with R^2 of 0.78 and 0.76, respectively. The yield simulation for Dimbasinia site is in progress.

With regard to Ethiopia, the proposed integrated modelling approach to study crop insurance system used simulated maize yield as input into the following formula to calculate indemnities for Lemo site in Southern Nations Nationalities region. The indemnities are computed based on the yield-index insurance coverage levels ranging from 50% to 100% (full coverage) compared to no coverage. This is done for a specified price premium and by calculating the expected indemnity given the specified yield distribution. Non-parametric distributions such as the empirical distribution and the kernel density estimator, which perform better than parametric distributions, are used to fit the simulated historical yields generated by the APEX model and compute the average yield. The fair premium being the expected indemnity that will be paid for each policy. Individual realized indemnities are calculated as:

*Indemnity = max(0, Price * (Average Yield * Insured Fraction – Realized Yield)*

Where: Price is the price to be paid per unit of yield shortfall,

Average Yield is the 32-year average simulated by APEX,

Insured Fraction is the insurance policy or level of coverage, such as 0.50, 0.55, etc.

Realized yield is a random variable with the probability distribution.

The expected indemnity (i.e., fair premium) for each coverage or insured fraction is calculated by numerically integrating under the indemnity formula above. The insurance policy pays off if the Realized Yield is less than the insured level (average yield * insured fraction).

Results on premium and indemnity schedule

Simulation appears to be a better approach to evaluate and rank risky crop insurance scenarios or alternatives for their feasibility. This section presents the simulation results for different scenarios and calculates the indemnities associated with the different insurance coverage levels or insurance policies and their premiums. The results provide an assessment of the level and probability of payment in cases of a yield loss. The results indicated that the best alternative (when purchasing a yield-index insurance in the area around Lemo district) is to buy the 100% coverage level. Results showed that the probabilities of earning an indemnity decreased from 85% to zero percent coverage level with no indemnity in the range of 70% to 0 percent coverage levels (Table 1). For the full insurance policy scenario, although the cost of the premium is high, there is a 67% probability of being paid an indemnity in the case of a yield loss (yield below the average/index) up to an amount of 3,014 birr per household. The probability of payment decreases to 15% for an insurance policy covering up to 85% of insured yield and to 7% probability for a 75% coverage level. Simulated values for a coverage level ranging from 50% to 70%, yield no probability of payment.

Table 1. Simulated premiums and probability of paying an indemnity

Scenarios	*Levels of coverage (Fraction)*	*Per Hectare Premium (ETB)*	*Probability of Indemnity*	*Range Indemnity pay (ETB)*
Full Insur. Policy	1	795	67%	0 - 3,014
No Ins 0.0	0	0.0	0%	0
Insur 0.5	0.5	0.0	0%	0
Insur 0.55	0.55	0.0	0%	0
Insur 0.6	0.6	0.0	0%	0
Insur 0.65	0.65	0.0	0%	0
Insur 0.7	0.7	0.0	0%	0
Insur 0.75	0.75	19	7%	0 - 494
Insur 0.8	0.8	62	10%	0 - 998
Insur 0.85	0.85	118	15%	0 - 1,502

The full distribution of all simulated values for indemnity payment are presented in the Figure 4 which shows that the probability of payment increases with the level of coverage. The insurance policy with full coverage has the highest probability of getting an indemnity in case of yield loss. Households with a full coverage insurance policy have a 50% probability of getting an indemnity payment of 630 birr or less in case of a yield loss while the probability of being paid around the same amount stands at 90% for households with an 85% coverage insurance policy. As for households with a 75% coverage insurance policy, the probability of getting an indemnity payment of 630 birr or less in case of a yield loss stands at a 100%.

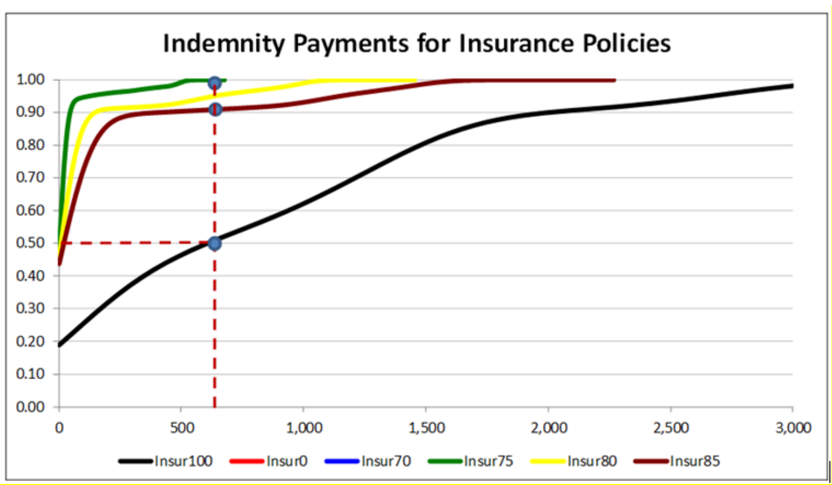

Figure 4. Cumulative distribution of indemnity payment for insurance policies, Lemo Ethiopia

Annex 7. Irrigation-nutrition linkages assessment Mali

Keys initial findings from the irrigation-nutrition linkages study in Mali include:

- **Farmer income and crop production**: Only 7% of farms with no access to irrigation engaged in farming during the dry season, but 51% of the irrigated households did. On average, crop income of households that irrigate was about 22% higher than non-irrigators. Since there were no large differences in crop income during the rainy season by irrigation status, the income differences are likely to be the result of the income generated during the dry season and from more diversified production. While almost all farmers engaged in cereal production, 50% of irrigators produced vegetables as opposed to only 6% of non-irrigators. Differences in fruit and tuber production were also statistically significant.
- **Market participation**: About 50% of the crop production of irrigating households was sold as opposed to 30% of the crop production of non-irrigators. Specifically, on average, while irrigators sold 60% of their cowpeas production, non-irrigators sold about 20%. Irrigators also sold a higher percentage of sorghum, rice, corn, peanut, and chilis. No differences were found in millet.
- **Employment**: On average, irrigating households employed twice as much as non-irrigating households. Differences in family and hired employment by household irrigation status was a result of employment in the dry season. While no significant differences were found for the rainy season, during the dry season, irrigating households had 56 family labor days and 29 hired labor days as opposed to almost no labor days in non-irrigating households. For irrigating households, family members seemed to have worked more labor days during the dry season than in the rainy season.
- **Dietary quality:** Households with irrigation had significantly better dietary quality and diversity than non-irrigators. While almost 100% of irrigating and non-irrigating households consumed cereals, households that irrigate consumed more vegetables, fruits, meat, eggs, fish, legumes, root crops and milk. Sugar had a very high consumption in all households – about 90%. Studies show that the relationship of higher production diversity and dietary quality is not straightforward and could be also a result of higher household income.

Annex 8. Identify entry points for the improved diffusion of small scale irrigation

In March 2021 IFPRI implemented two stakeholder workshops for identifying stakeholders in the small scale irrigation (SSI) technology diffusion space as well as their interlinkages. The first, national, workshop took place in Bamako and involved government officials, NGOs, researchers and funders. The second workshop, held in Sikasso included representatives from the same actor set with a larger number of organizations representing farmers. The national workshop identified 73 different actors who are linked to the diffusion of SSI and the regional workshop identified 48 actors.

Figure 1 shows the information flows across stakeholders identified in the national workshop. It depicts two almost parallel sets of actor networks, one around the two key government agencies, DNGR (National Directorate of Rural Engineering) and MAEP (the Ministry of Agriculture, Livestock and Fisheries); and the other around a series of farmer associations, such as the Association of female market gardeners and Inter Professions.

Key constraints identified by participants include the low competence and specialization of the actors involved in the sector, especially private actors, poor dissemination of irrigation technologies to beneficiaries; non-adaptability of the SSI technologies disseminated; financial constraints of beneficiaries; high cost of technology and high cost of credit; low negotiation capacity of farmers' organizations; and weak synergy and interaction of actors involved in the dissemination of small-scale irrigation technologies in the region; variable policy support; and poor capacity building of farmers. The participants proposed a number of solutions to accelerate the dissemination of SSI technologies including, including to create a framework that more strongly links across key stakeholders in the SSI sector; the identification of ways to lower technology cost; and the strengthening of capacities of advisory services.

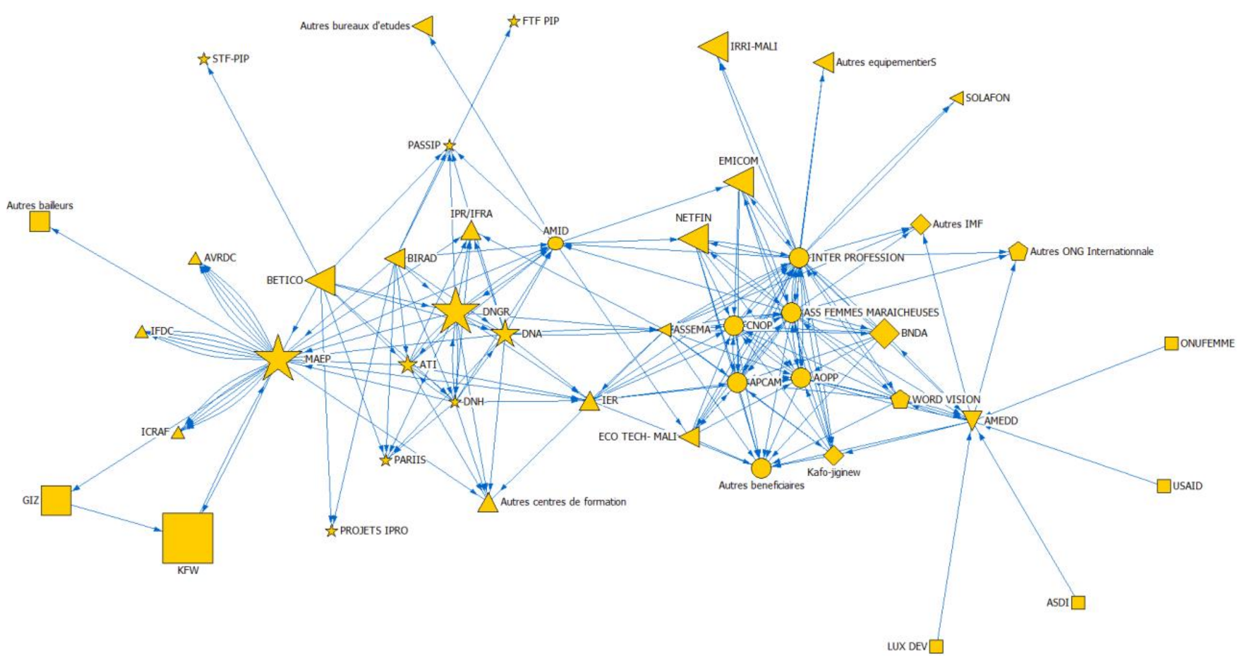

Figure 1. Net-Mapping of the diffusion of small scale irrigation technologies, Mali

Annex 9. Assessment of watershed and SSI interventions on nutrition and resilience under PSNP

Background

This study assesses the impacts of watershed rehabilitation and irrigation interventions on food security and resilience in the Productive Safety Net Program (PSNP) woredas of Ethiopia. The case study woredas/watersheds are located in Tigray, Amhara, and Oromia regions, and Dire Dawa administration (Figure 1). During this reporting period, the IDSS team conducted two main activities: 1) use of high-resolution remote sensing-based Normalized Difference Vegetation Index (NDVI) analysis to detect the changes in vegetation greenness, and 2) applying a biophysical models to assess changes in soil loss, ground water recharge, and surface runoff generation due to the implementation of the watershed interventions in the selected watersheds. Detailed impact analysis is conducted in seven watersheds located in different regions and implemented by various partners. The watershed selection was conducted with joint activity with IFPRI team and considers availability of secondary data, size of watersheds (>7000 ha), size of irrigated area within the watersheds (>40 ha), availability of different types of interventions, and availability of development maps.

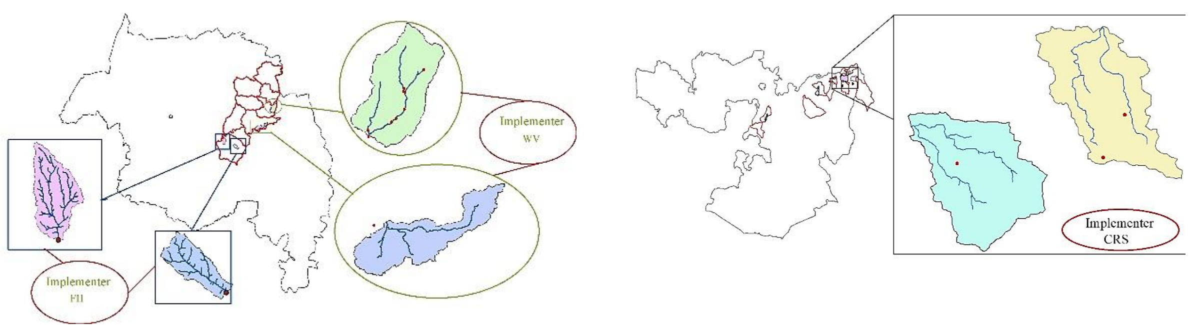

Figure 1: Location of selected BHA watersheds for the detailed biopysical and socio-economic analysis.

Remote sensing-based change detection

Remotely sensed images before (1984-2005) and after (2006-2020) the watershed intervention implementations (i.e., 2006 in the case of Feresmay) were used to detect changes in greenness due to the interventions. Possible improvement in vegetation cover may be considered as a proxy for enhancement in soil moisture and soil fertility, which may help to improve agricultural productivity and food security in the BHA woredas/watersheds. High spatial and temporal resolution Landsat level 2 geometrically images were used to get the time series 16-day Normalized Difference Vegetation Index (NDVI). The assessment used six subareas with treatment and six adjacent control subareas (each having an area of ~9 ha) (Figure 2). Other than the interventions, the control subareas have more or less similar biophysical settings (e.g., elevation, slope, and climate) to that of the treated subareas. Such arrangement helps to properly detect attributions to the interventions. Areal average NDVI values were extracted for the treated and control subareas and clustered into two datasets representing before (1984-2005) and after (2006-2020) intervention implementations. The NDVI time series of each subarea were fitted to a polynomial function of order four and compared to analyze the change of greenness due to the watershed interventions (Figure 3). The result showed that implementation of BHA watershed interventions improves watershed greenness in the dry and wet seasons (Figure 3) as well as in drought years.

The evaluation process was completed for the dominant types of interventions for each selected watershed. Long-term Landsat based NDVI were processed to assess the change in vegetation greenness "*before*" and "*after*" intervention, during "wet" and "dry" seasons, and drought/shock years. Overall, the findings of the remote sensing analysis indicated an enhancement in vegetation greenness due to the interventions although it varies by intervention and watershed. Reduction in vegetation greenness is also observed in some of the watersheds. The degree of enhancement depends on multiple factors, e.g. the type of the interventions implemented in a watershed. Area closure enriched with plantation and other PSNP structures, and irrigation interventions were relatively more effective in enhancing the vegetation greenness in most of the watersheds. The seasonal analysis showed enhancement in vegetation greenness during the dry season; however, consistent vegetation enhancement was not observed during the wet season. Figure 3 shows results of the vegetation greenness "*before*" and "*after*" interventions for Zergawido watershed of the FH site.

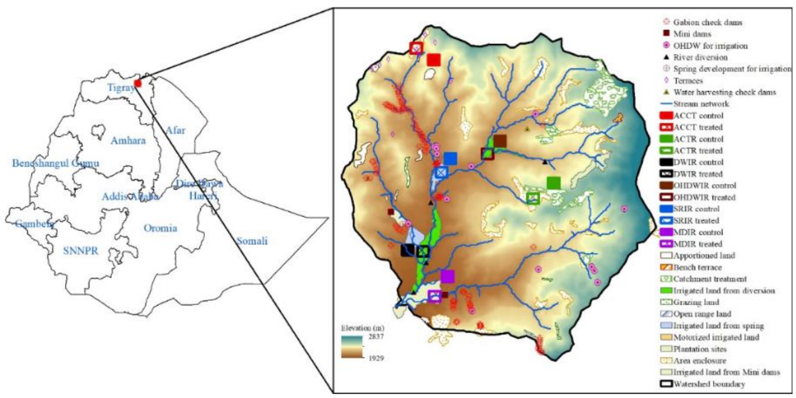

Figure 2: Location and topography map of the Feresmay watershed in Tigray. The watershed map shows implemented interventions as well as treated (open boxes) and control (sold boxes) subareas.

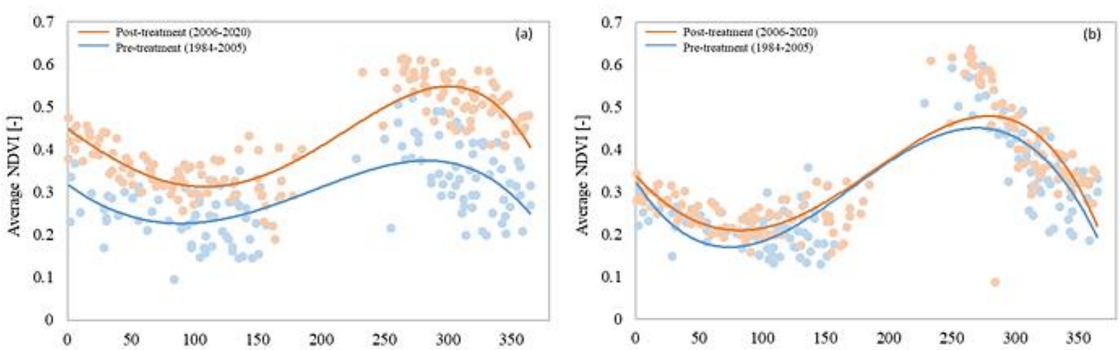

Figure 3: Pre- and post-treatment Normalized Difference Vegetation Index (NDVI) for (a) treated and (b) control subareas.

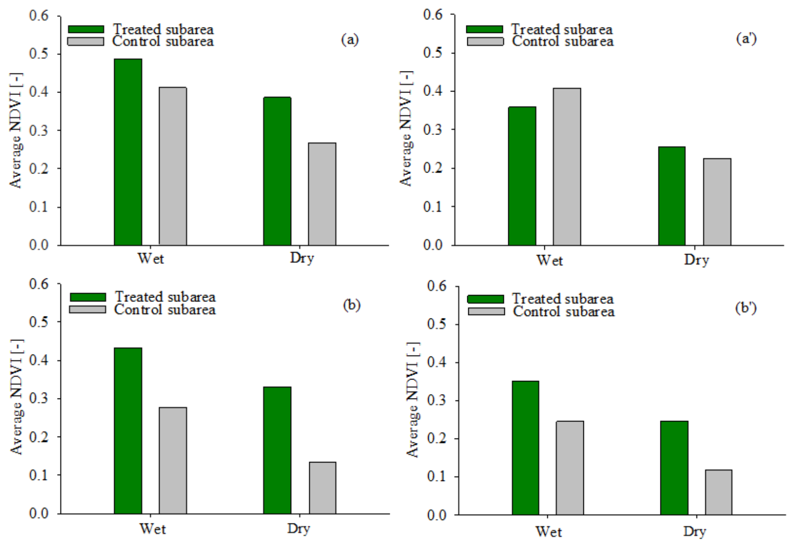

Figure 13: Seasonal average NDVI for after-intervention analysis (a and a') and before-interventions analysis (b and b') in treated and control subareas.

Figure 3: Average NDVI "before" and "after" area closure (a), irrigation (b), PSWCS (C) interventions and watershed level analysis (d). PSWCS includes hillside terrace, soil bunds, stone faced soil bunds, trench, cutoff drain, and waterways. The horizontal line in each box indicated the median value.

RUSLE based soil loss estimation and change detection analysis

RUSLE method was employed to estimate the annual soil loss to assess if the interventions reduced soil erosion or not in the Feresmay watershed. The soil loss was estimated before (2006) and after (2019) the implementation of the interventions. The activities in the RUSLE analysis include developing high resolution landuse/landcover maps for 2006 and 2019, estimating the RUSLE parameters, quantifying the annual soil loss representing the time period before and after interventions, and prioritizing potential soil erosion prone areas to suggest future watershed interventions. Results showed that soil erosion reduced after the implementation of the interventions (Figure 4).

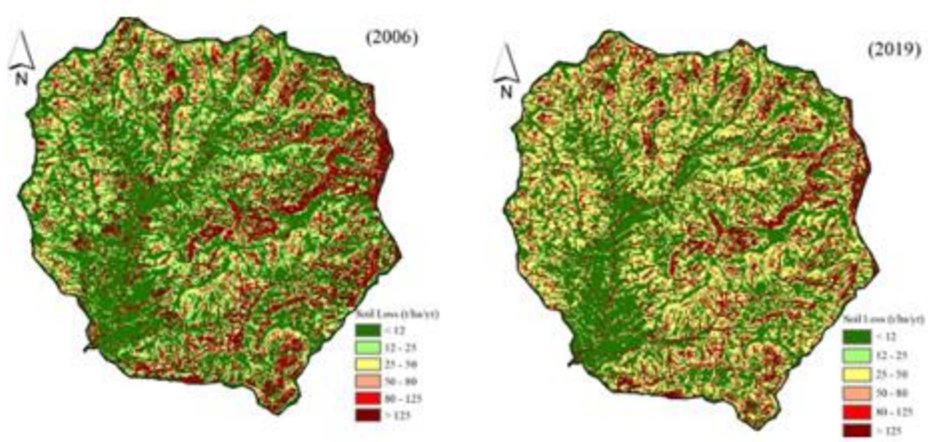

Figure 4: Annual soil loss before (2006) and after (2019) implementation of watershed interventions in the Feresmay watershed.

Biophysical modeling approach of change detection

Although there is a big challenge of lack of observed streamflow and other data to calibrate and validate the model, we followed parameter transfer and soft calibration approaches to develop a reasonable biophysical model for each selected watershed. Except CRS watersheds, the other sites are located within or adjacent to the Tekeze basin where there is streamflow measured data to calibrate the model parameters and transfer the parameters to the study watersheds. The model parameters were first transferred to another gauged watershed for verification purposes. The result showed the good performance of the model with R-square and Nash–Sutcliffe (NS) values of 0.81and 0.74 respectively. We also used literature-based measured sediment values and used for additional soft calibration of the model. Accordingly, we developed calibrated baseline models for a total of 12 watersheds (i.e., 4 WV, 4 CRS, 3 FH and 1 REST). Some of the watersheds in WV sites are adjacent to each other and treated as subbasins in a bigger watershed.

During this report period, the biophysical based evaluation of the interventions was completed for Feresmay watershed in Tigray and on progress for the other watersheds. The preliminary result obtained for Feresmay watershed shows insignificant improvement at watershed scale level "*before*" and "*after*" analysis while pronounced enhancement were observed at subbasin where the interventions are implemented.

Annex 10. Short term capacity development

Table 1. Short Term Training Events

Country	Brief Purpose of Training	Number Trained		
		M	F	Total
Mali	Strengthen the technical capacity of local vegetable seed producers. Topics included vegetable breeding, including different crossing methods, seed legislation, seed production methods, crop management, soil fertility management, pest management, and irrigated water management, including the pros and cons of different irrigation methods.	16	4	20
Mali	Strengthen the technical capacity of local vegetable seed producers. Topics included vegetable breeding, including different crossing methods, seed legislation, seed production methods, crop management, soil fertility management, pest management, and irrigated water management, including the pros and cons of different irrigation methods.	19	5	24
Ethiopia	One-day learning event to share experiences of the ILSSI irrigated fodder work and developments on the ground to extension officers, development partners and lead farmers. The event also involved participatory variety scoring/evaluation to take into account farmers' own preferences to identify promising varieties for scaling.	13	3	16
Ethiopia	Workshop to share experiences and developments on the ground regarding irrigated fodder development, and conduct participatory variety evaluation	23	3	26
Ethiopia	Training for farmers on basic practical skills on the establishment and management of different irrigated fodder crops. Topics included plot preparation, water lifting technologies, irrigation practices, and fodder crop management. Farmers received practical demonstrations and visited well managed irrigated fodder plots to share experience.	75	27	102
Ethiopia	Training covered groundwater as a source for irrigation, challenges affecting groundwater use and sustainability, and engagement with farmers on these topics. The training was followed by a field trial and a feedback session.	7	1	8
Ethiopia	IDSS local capacity development on Soil and Water Assessment Tool (SWAT), Agricultural Policy Environment eXtender (APEX), and Farm Income Simulator (FARMSIM) as well as their integration.	63	12	75
Ethiopia	IWMI and Bahir Dar Institute of Technology (BiT)/Bahir Dar University organized semi-virtual trainings on human centered design, a field tour, mentorship, and a pitching competition from March 15th to June 30th, 2021 as part of the Agri Hackathon.	22	10	32

Annex 11. Data and publications

Datasets

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'Operationalizing farmer-led irrigation development at scale: How to design your interventions to build sustainable and climate-resilient food production systems', September 2021, co-organized by AUC, FAO, IWMI, WB-GWSP (846 registrations; 439 participants).

Panel discussion. UN System Standing Committee on Nutrition paper. Topic: Specific linkages between small-scale irrigation and nutrition and bring insights from the field on how irrigation is transforming rural livelihoods.

Stockholm World Water Week 2021 (August 2021)

- 'Irrigation and socio-environmental resilience: Finding confluence between strategy and disaster'
- 'Self-supply's potential for increased resilience and water security'
- 'The role of water in transforming Africa's value chains'
- 'Accelerating water and food security: The role of UNFSS'

"Small-Scale Irrigation, Resilience and Nutrition: Can we have it All?" 2020 International Borlaug Dialogue, 13 October 2020. Side event 2020 World Food Prize.

UN Food Systems Summit: IWMI, TAMU, IFPRI, the World Bank, GWP, African Union submitted Water Game Changer 5.20 'Adaptive human-centric approach to resilient and sustainable water management' under Action Track 5, which combined farmer led irrigation, innovative financing, water storage and water-reuse topics.

Webinar: "Potential and options for irrigated fodder production shared with policymakers and practitioners in Ethiopia". 2 December 2020. Co-organized event with the Livestock Systems Innovation Lab (LSIL) and ILRI, researchers presented results on potential and options for irrigated fodder production to policymakers and practitioners in Ethiopia. Over 30 participants joined representing science institutions, development and donor organizations, and government.

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Annex 12. Innovation Transfer and Scaling Partnerships

Phase 1: Under Research

1 - Improved vegetable seed production

Category: Social Science Research
Description: The project aims to strengthen the capacity of local seed producers to produce quality vegetable seed. This involves biological innovation (germplasm), but also improved management practices and institutional innovation. The innovation is therefore difficult to categorize.
Steps Taken: This field is pulled from the Technologies & Management Practices module.
Next Steps: We are supporting a sub-sample of vegetable seed producers with detailed technical assistance in order for them to adopt improved irrigation technologies.
Partnerships Made: No new partnerships were created.
Countries: Mali

2 - Screening forage varieties for water and nutrient efficiency

Category: Biological
Description: Accessions of Napier, Brachiaria and Panicum are under investigation to identify varieties with the highest water and nutrient use efficiency. The objective is to avail forage varieties that fit well the small-holder conditions where water and nutrients constrain fodder production. After the varieties are screened, they will be evaluated further by farmers and then released for wider scaling.
Steps Taken: This field is pulled from the Technologies & Management Practices module.
Next Steps: This field is pulled from the Technologies & Management Practices module.
Partnerships Made: Bahir Dar University; Andassa Research Center
Countries: Ethiopia

3 - Yield-index insurance

Category: Social Science Research
Description: To increase resilience of farmers against climate shocks, a yield-index insurance is being developed based on policy for Ethiopia and Ghana using an integrated approach of biophysical and socio-economic simulation models to evaluate potential indemnities that would be paid to farmers in case of crop losses due to climate shocks.
Steps Taken: This field is pulled from the Technologies & Management Practices module.
Next Steps: under development
Partnerships Made: target partnership with private sector both in Ethiopia and Ghana
Countries: Ethiopia

Phase 2: Under Field Testing

1 - Interactive online tool to assess solar based irrigation suitability in SSA

Category: Management Practices
Description: The tools targets private sector and public sector entities to provide a spatial overview of potential suitable areas for solar based irrigation expansion using remote sensing and other spatial information taking into consideration the water source and the pump characteristics. It can support private sector companies in complementing their market analysis with a spatial overview of potential areas for expanding their businesses either directly our through local distributors.
Steps Taken: This field is pulled from the Technologies & Management Practices module.
Next Steps: Investigating the commercialization of the tool with private sector
Partnerships Made: Private sector - Future Pump and Powering Agriculture - GIZ
Countries: Ethiopia, Ghana, Mali

Phase 4: Demonstrated uptake by the public and/or private sector

1 - Analyzing the enabling environment to enhance the scaling of irrigation and water management technologies: A tool for implementers

Category: Social Science Research
Description: Aimed at implementers – including practitioners, government representatives, private sector actors and donors – the tool guides users through a series of structured steps that provide a clear understanding of the enabling environment in which the scaling processes for water solutions are embedded. This can be achieved by conducting an analysis to identify enablers and hinderers influencing farmers' adoption of irrigation and water management technologies, and introducing measures to ensure success. This tool provides a structured guide to carrying out this analysis in a specific context.
Steps Taken: This field is pulled from the Technologies & Management Practices module.
Next Steps: Step 1: Draft the tool Step 2. Co-refine the tool with participants/potential users via training workshop Step 3. publishing Step 4. Scaling
Partnerships Made: IWMI in leveraging with the Technologies for African Agricultural Transformation – Water Enabler Compact (TAAT-WEC) has developed this tool.
Countries: Other

Annex 13. Success Stories

Ethiopian dairy cooperatives use irrigation for forage production, increasing farmers' incomes and resilience

Irrigated fodder production is a recent development in Ethiopia. But now, after years of collaboration with the Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI), both individual farmers and dairy cooperatives have started using small scale irrigation techniques and new forage varieties to produce fodder year-round for livestock feeding.

Ethiopian dairy cooperatives use irrigation for forage production, increasing farmers' incomes and resilience

by Aberra Adie

"Our collaboration with the ILSSI project has enabled us to increase our milk production and sales considerably," said Alemu Demoze, the chairman of the Genet Lerobit Dairy Cooperative in Bahir Dar Zuria district, Ethiopia.

Image 1 Mr Alemu Demoze, chairman of Genet Lerobit Dairy cooperative (Photo credit: ILRI/Fikadu Tessema)

Irrigated fodder production is a recent development in Ethiopia. But now, after years of collaboration with the Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI), both individual farmers and dairy cooperatives have started using small scale irrigation techniques and new forage varieties to produce fodder year-round for livestock feeding. ILSSI has provided technical support to the dairy cooperatives in its project sites, which has helped these entities to establish a new milk collection center, forage seed store, and sales shops.

Image 2. Newly constructed milk collection and forage seed sales shop by Genet Lerobit dairy cooperative (Photo credit: ILRI/Fikadu Tessema)

Cooperatives boost incomes and value chains

Alemu explained that membership numbers in the Genet Lerobit Dairy Cooperative have increased from 57 members 3 years ago to 180 now due to the growing interest in irrigated fodder production and the market opportunities created for fluid milk: "*Currently, we are supplying about 300 liters of milk daily at a price of 22 birr (US$0.50) per liter to a milk processor in Bahir Dar town. This volume of milk is up by more than 50 percent from what we used to supply few years back.*"

The cooperative's engagement in forage seed multiplication and marketing is expected to provide an additional source of income for its members, while also strengthening the fodder value chain in the communities.

"*We have allocated 1.5 hectares of dedicated land for forage seed multiplication and also formed farmer interest groups, which show interest in multiplying forage seeds and planting materials on their own land and supply to the cooperative,*" said Alemu. According to him, the cooperative is planning to use both individual farms and the land secured through the cooperative as a source of forage seed and planting materials.

Image 3 Mr Alemu Demoze (right) standing in front of the newly constructed milk collection center and feed shops (Photo Credit: ILRI/Fikadu Tessema)

Explaining further the cooperative's preparations to strengthen the irrigated fodder value chain, he added: "*Through the partnership we have with ILSSI, we have constructed a forage seed store, milk collection and processing rooms, as well as sales shops. These facilities will considerably increase our market share and incomes in the near future.*"

The cooperative management believes they are now in a good position to increase dairy production in the community using irrigated fodder technologies and new market opportunities created through the collaboration with ILSSI and other development actors. "*We are in discussion with the local extension office so that they can support us in certifying the forage seeds that we plan to produce this season. We are also in* *discussion with the livestock and fisheries sector development project to create market linkages for forage seeds,*" Alemu explained.

Providing protection against COVID-19 disruptions

Habebo Dairy Cooperative, located in the Lemo district of Ethiopia's Southern region, is another entity engaged in irrigated fodder development. The cooperative provides services to its members by collecting fluid milk and processing it into butter and cheese, which allows them to sell these higher-value products to consumers. Over the past three years, the support the cooperative members received from ILSSI enabled them to grow their capacity and become more resilient to market fluctuations.

Image 4 Ms Aberash Tamre, chairman of Habebo dairy cooperative (Photo credit: ILRI/Tigist German)

"*Our collaboration with ILSSI came at a critical time for us,"* said Aberash Tamire, the chairperson of the cooperative. *"When the COVID-19 pandemic disrupted market chains, we were able to cope with the problem by processing our milk into shelf-stable and easily transportable products, such as butter and cheese. Other farmers who didn't have the capacity to process milk were seriously affected by the movement restrictions and market disruptions for fluid milk.*"

This cooperative has managed to construct a well-designed milk processing room, a forage seed store, and sales shops in their compound under the private sector partnership with ILSSI.

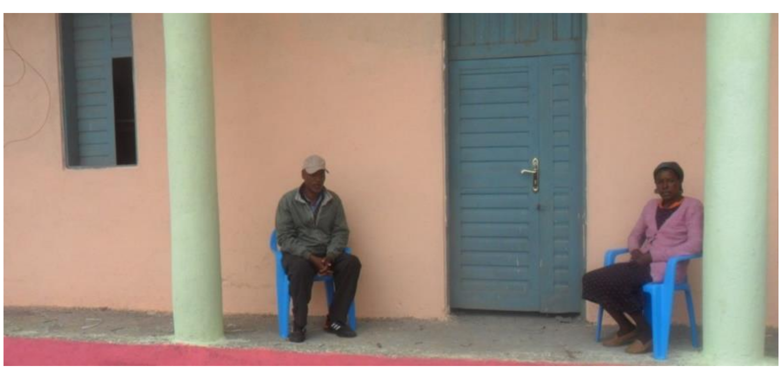

Image 5. Habebo dairy cooperative management members in their newly set up milk collection and shop center (Photo Credit: ILRI/Tigist German)

"*Our members are highly indebted to the support provided to grow our capacity. This collaboration with ILSSI has also motivated other farmers to apply for cooperative membership, and currently the total membership has reached 220 households, which is up by 40 percent compared to two years ago. Some of the newcomers recently bought crossbred cows and joined us,*" explained Aberash.

Tackling land and water challenges

In the areas where these two dairy cooperatives are located, land remains a major constraint to agricultural productivity. Competition is high for land to produce food crops and fodder. However, adoption of irrigated fodder production has helped ease the competition for land, as farmers are now able to produce fodder year-round on a small plot of land.

In addition, ILSSI is working with national partners to provide alternative forage varieties that can be grown with minimum water and nutrient input while at the same time supply the needed fodder for farmers' livestock. Adoption of the new varieties would further ease the pressure on natural resources, especially water. Cooperative members are participating in the evaluation of the new forage varieties for wider scaling.

Finally, under ILSSI, ILRI and local partners have planned a series of training programs to strengthen the capacity of the cooperatives in forage seed multiplication and marketing businesses. The impact of the ILSSI intervention is now visible in the project sites: "*We are very happy at the moment because we are making tangible progress in improving our income and livelihoods,*" concluded Aberash.

Market segmentation - a key for scaling partnership to create demand-supply linkages for solar-powered irrigation pump and pay-as-you-own financing in Northern Ghana

In 2020, IWMI, the Africa Research in Sustainable Intensification for the Next Generation programmes (Africa RISING), and the Innovation Lab for Small Scale Irrigation (ILSSI) developed a market segmentation framework and conducted the segmenting for solar-powered irrigation pumps and pay-as-you-own (Pay-own) financing in Northern Region Ghana. The market segmentation is based on farmers' access to land, water, irrigation and production arrangements, financial capital and potential, and product preferences. The study showed that by identifying and segmenting customer groups, companies can target their products and services to the right people, in the right way, opening-up opportunities for growth, informing product development and improving customer retention.

Based on the results from the market segmentation in northern Ghana, IWMI and Pumptech have established the scaling partnership to create demand-supply linkages for the bundles of solar-powered irrigation pump, pay-own financing and pre- and post-services within the Upper East Region. A series of demand-supply linkages workshops was organized in the Upper East Region, resulting in establishing three sale and service partner networks in different zones of the region. These networks involve 219 customary leaders, community volunteers, farmers, input dealers, irrigation equipment distributors, borehole drillers and mechanicals and agricultural extension agents. As a result of the partnership, Pumptech has opened the new branch office in the Upper East with the Ministry of Food and Agriculture to address the increased demand of farmers in the region.

The various pay-own payment schemes tailored to different market segments as well as the use of data-driven tools developed by IWMI (e.g., solar suitability mapping, market segmentation) to de-risk their investment into solar-powered irrigation pump and pay-own financing have won the further investment from GIZ to support Pumptech's further solar-powered irrigation market development in Ghana. The investment values 628,966.00 GHC. Further, through further support from GIZ-Market Oriented Agricultural Programme in North West Ghana (MOAP NW), the partnership is expanded into the Upper West region by October 2021.