Feed the Future
Innovation Laboratory for Small Scale Irrigation

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Norman Borlaug Institute for International Agriculture,

The Texas A&M University System (Lead Institution)

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International Livestock Research Institute (ILRI)

International Water Management Institute (IWMI)

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Executive Summary

ILSSI made progress toward Objective 1, Identify and Test Approaches to Sustainably Scale SSI through Reducing Constraints and Strengthening Opportunities for Access. Notably, private sector partner sub-awards with equipment supply companies and cooperatives were finalized, and joint research on scaling commenced. In addition, ILSSI research supported a greater understanding of the information needs of the private sector and enabled the project to present relevant information in a format useable to the private sector. In addition, ILSSI documented cases and extracted lessons on scaling through irrigated value chains, and in turn, contributed lessons on good practices to scaling investments across Sub-Saharan Africa (SSA). ILSSI continues research on the constraints and potential policy-level approaches to address barriers.

Progress on Objective 2, Identify and test approaches to scale SSI to be sustainable and support resilience, proceeded slower than anticipated, following COVID19 related restrictions on fieldwork and travel. ILSSI continued scientific analysis on the environmental impact of SSI, and linkages between environmental and human resilience, through the application of models to the understanding of water quality implications of SSI adoption, based on projected adoption with Ethiopia as the case study, as well as Water Accounting methods on water allocation and risks to scarcity in West Africa. ILSSI also continued set up for an in-depth analysis of climate change and variability, with regard to natural resource and water scarcity, particularly in West Africa, which applies to analysis on vegetables, vegetable seed production, and cocoa production. ILSSI partners slowly expanded work in Mali with all protocols set up, but found implementation hindered with COVID. Partners were able to initiate seed system and irrigated value chain analysis, though limited largely to desk study.

Progress toward *Objective 3, Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production*, also was hindered by COVID19, as this area of inquiry relies heavily on community level engagement and household level data collection. Key activities achieved included support to private sector companies to operationalize social equity aims in the market and provide inputs into national and global investor planning related to farmer-led irrigation. As both development investors and companies seek to catalyze and speed up commercialization amid an absence of governance structures for local water resources, ILSSI has prepared the protocols to analyze governance issues, and pilots' local level approaches. Additional protocols were also prepared, and desk work was completed related to gender, multiple uses of water, and nutrition, including but not limited to irrigated fodder value chains. Most direct fieldwork was suspended in March 2020.

Through initial in-person and then virtual engagement, ILSSI continued progress on Objective 4, which related to achieving impact of research results through human and institutional capacity development, and outreach and knowledge sharing. Communications and outreach efforts were strengthened on-line, though HICD activities and events declined compared to previous years. Nonetheless, ILSSI research-based evidence was shared through numerous platforms and events and provided input to decision-makers at multiple levels, keeping ILSSI on track to ensure impact after project closure.

The research scope and number of project countries expanded during the reporting period through buy-in awards and funded complementary projects in Feed the Future target countries. ILSSI also expanded engagement with other USAID supported programs and projects as a knowledge partner.

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 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, while continuing some analysis of data from Tanzania. ILSSI researchers and partners have added Nepal as a project country this year 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). ILSSI works in collaboration with scientific institutions, including the International Water Management Institute, International Food Policy Research Institute, International Livestock Research Institute, and the World Vegetable Center. We have added private sector partners in Ghana with PEG Africa/Ghana and in Ethiopia with Rensys Engineering. This report describes progress toward project objectives in fiscal year 2020, which is the seventh year of ILSSI's 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 and maintained sub-agreements and unfunded collaborations. Mitigation actions have been taken to improve the budget burn rate and strengthen monitoring of sub-agreement expenditure rates, albeit allowing some adjustments due to COVID19.
- ME clarified within TAMU the process for review of ethical human subject research.
- New sub-agreement developed with the World Vegetable Center (focus on Mali).
- ME managed a competitive process and executed agreement for two private sector sub-agreements (1 each in Ethiopia and Ghana). In the process, we obtained an IEE Amendment and an updated Environmental Mitigation and Monitoring Plan.
- Reconstituted the ILSSI External Advisory Committee (EAC); 4 members represent multiple subject expertise, a range of professional experience and gender balance.
- In-person meeting of the Project Management Committee and EAC was postponed, due to COVID19.
- ME engaged virtually and in-person with the USAID Missions in Ghana, Ethiopia and Mali to ensure that ILSSI research responds to the Mission's needs and aligns with Mission funded activities. Mission representatives attended ILSSI convened workshops. Mali USAID Mission supported the IFPRI field visits in Mali; the Mission subject interests have been integrated into the research activities (notably on water quality in relation to farmer-led irrigation).
- Prior to travel restrictions, the ME met with USAID in Washington, DC to present an update on the project, and also with the Office of U.S. Foreign Disaster Assistance to discuss activities in Mali.

Activity 0.4. New funding engagement and initiatives

In addition to the Mali buy-in, the Bureau for Humanitarian Assistance (formerly Food for Peace) provided buy-in for Ethiopia to assess irrigation and land management practices under the Productive Safety Net Program (PSNP), particularly with IFPRI and the Integrated Decision Support System team at TAMU. ME also engaged with the Malawi USAID flagship program Agriculture Diversification (AgDiv), reviewed actions in AgDiv project sites, and developed a scope of work; an assessment of AgDiv supported irrigation, and sustainable land management activities will be conducted in Malawi under a sub-contract.

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

Summary of Progress on Objective 1*: All private sub-awards and some non-funded partnerships are in place with equipment supply companies and cooperatives; ILSSI has achieved a greater understanding of the information needs of the private sector, learning what and how to present information; Documented cases and extracted lessons on scaling through irrigated value chains have contributed to scaling investments across SSA; Continued research on the constraints and potential policy-level approaches to address barriers.*

Activity 1.1: Identify upscaling opportunities for resilient SSI systems

Sub-Activity 1.1.1. Joint research scaling activity private sector entities (equipment suppliers, irrigated fodder VC actors)

Texas A & M concluded the RFA process and executed signed agreements with two private sector partners, PEG Africa in Ghana and Rensys Engineering in Ethiopia, commencing in July 2020. Internal workshops on business model canvas development and marketing strategies were held in country with each partner in early 2020. To strengthen the potential impact, the USAID Investment Support Program (ISP) enabled ILSSI to work with Dalberg; Dalberg developed lessons for the private sector partners across key components for scaling, and also provided templates for a farmer business case analysis and a contextualized market assessment for expanding sales.

Between July and the end of September, PEG Africa completed the first two milestones in the performance-based agreement, submitting a business strategy and market scoping assessment. In addition, the company hired a project manager to expand the irrigation product distribution network, and introduced the pump solutions to about 100 farmers through three Water Sales Associates. PEG also established 1 pump distribution center in the Upper East Region to reach farmers in more remote areas that fall within the FTF Zone of Influence. PEG also began marketing campaigns (community announcements, exhibitions and radio interviews); the in-depth marketing strategy is still under design and M & E will need to be done to identify most effective ways to reduce the costs of reaching clients. Through USAID, PEG Africa engaged with the ADVANCE II project led by ACDI VOCA, developed a type of MOU to collaborate and in a few weeks sold 6 pumps and 1 sunverter to 5 farmers. To ensure strong after-sales services, PEG also trained new and existing field technicians on pump installation and panel configuration. Through field visits, PEG identified that some small scale irrigators in peri-urban areas are constrained by land tenure insecurity, and though financially capable of purchasing the solar pump, lack land-based collateral; rural farmers on the other hand, do not have the ability to pay for the pumps but are not constrained by land tenure insecurity. In addition, fragmentation of farm plots in rural locations creates challenges for irrigators to pool resources to jointly invest in solar pumps. In response, PEG has begun to revise its market segmentation and targeting, as well as the financial products for the asset based financing. Notably, PEG is reducing the initial deposit from 20% to 10% downpayment; this is consistent with other case studies around Africa that highlight the downpayment as the key constraint to irrigation equipment access. In addition, ILSSI has begun to create linkages between PEG Africa and other projects with farmer networks in Ghana, including Power Africa Off Grid (PAOP) and an investment in the cocoa sector. These actions come just as the dry season commences in Ghana around October. In addition, PEG will implement a 'good payer bonus' to provide a10% rebate on monthly repayments.

Rensys in Ethiopia has faced numerous constraints under COVID19 measures and also with internal capacity. While IWMI, the ME, Dalberg and Power Africa Off-Grid have provided various forms of support to Rensys, the company has been unable to deliver milestones on schedule. The deadline for the initial milestones has been extended for Rensys, and the ME is monitoring progress. The Ethiopia Mission was informed of the issues.

Also in Ethiopia, ILRI has also now engaged in a knowledge partnership with private sector partners: three dairy cooperatives, two of which are all women members, have been selected, a fixed service agreement signed, and milestone-based "grants" awarded to strengthen the fodder value chain in the project sites. Emphasis of the performance structured agreements is to establish local forage seed systems, link farmer groups to the equipment supply chain for small scale irrigation technologies, and increase the linkages down the value chain to milk processing and marketing activities.

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

The private sector has expressed the need for scientific evidence and reliable suitability maps for small scale irrigation, but research institutions generally lack understanding of private sector needs and in particular, useable types and formats of information. Toward effective response to support the private sector, IWMI launched a qualitative online survey related to specific spatial information needs and other factors associated with restricting or enabling environment for small scale irrigation. The online qualitative survey launched (https://iwmisurvey.typeform.com/to/PKJYne) in February 2020 to remain open for one year; over 100 respondents have been engaged to date.

Following COVID19 issues, IWMI adapted research to conduct 25 semi-structured interviews with private sector companies and public sector agencies in Ethiopia and Ghana, and undertake a literature review. Initial findings were presented on 'Dynamics of small scale irrigation development: Subsidizing and capitalizing pathway of scaling', at the 2nd International Conference on 'Irrigation and Agricultural Development (IRAD 2020) (https://wacwisa.uds.edu.gh/wacwisa-holds-second-international-conference-on-irrigation-and-agricultural-development-irad-2020/) in Ghana [25-27 February 2020, University for Development Studies (UDS)]. Results are being drafted into a paper on 'Enabling private and public sector investments: What and how information supports scaling pathways?' The research highlights:

- Subsidy provision and technology transfer are driven by actors' technology promotion agendas rather than ensuring technology works for the targeted irrigation and farming system;

- Irrigation investment can be capitalized when the bundle of irrigation technology and services is provided to help farmers to minimize investment's risk and increase cash flow for continued investment; and
- Small scale irrigation development in Ghana can benefit farmers when the public and private sectors' investments, 1) meet farmers' demands, 2) bundle services and appropriate financial and organizational mechanisms, 3) share investment risk with irrigators.

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) & Activity 1.1.4 Validation of the suitability maps using available data from the private sector piloting

To improve scientific information delivery to the private sector, and into public sector planning and monitoring, IWMI refined the interactive online tool on land suitability for solar irrigation (http://sip.africa.iwmi.org/). To improve input data, strengthen resolution, and get private company feedback, IWMI signed agreements with Technoserve, PEG Africa, and Solarworks. IWMI also collaborated with a GIZ project to report on ' Solar irrigation market analysis in Ethiopia: Green People´s Energy'. Further collaboration is underway between IWMI and PEG Africa.

Sub-Activity 1.1.6. Develop irrigated fodder suitability map

The IDSS team identified a suitable area for irrigated fodder production in Ethiopia. The study was done for multiple fodder crops selected by ILRI and local stakeholder engagement activities. The selected fodder crops were Napier (Pennisetum purpureum), alfalfa (Medicago sativa), oats (Avena sativa), vetch (Lathyrus cicera), desho (Pennisetum pedicellatum). The suitability analysis was done by considering biophysical and socioeconomic factors. The suitability analysis indicated that the country has the largest suitable area for Desho production (31%) followed by Vetch (23%), Napier (20%), Alfalfa (13%), and oats (12%). The fodder suitability analysis disaggregated into the major river basins indicates that the largest basin in Ethiopia, the Abbay Basin (Blue Nile Basin) has the largest area suitable for fodder production followed by Genale-Dawa and Wabi-Shebelle. Abbay River Basin has the highest suitable area for Napier and oats while Genale-Dawa has the largest suitable area for desho, alfalfa, and vetch. Biomass production potentials under different agro-climatic settings and available blue and green water resources to produce biomass fodder were estimated. See Annex 1 for a description of methodology and results for scaling fodder production in Ethiopia. In addition, ILSSI held meetings in Ethiopia to get feedback on the potential interest; IFAD, the World Bank, USAID implementers (e.g. Land o' Lakes), and USAID Mission expressed interest to use the outputs in Ethiopia.

The collaboration included ILRI contribution of compiling and providing key factors that affect growth performance of representative fodder crops (Napier grass, alfalfa, Desho grass, vetch and oat). This activity was co-funded by the FTF Livestock Systems Innovation Lab. The results have been presented at the Livestock Systems conference and summarized in briefs produced by the Livestock System IL.

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

Sub-Activity 1.2.1. Constraints Analysis

IFPRI's paper on constraints to the adoption of small-scale irrigation technologies ('Hierarchical modelling of the constraints to irrigation adoption in Ghana, Ethiopia, and Tanzania') has been reviewed and resubmitted for publication.

Sub-Activity Activity 1.2.2: Role of credit constraints paper

IFPRI's paper on the role of credit constraints in adopting SSI technologies (Ethiopia and Tanzania) was published as an IFPRI Discussion Paper. This paper helped to fill a gap by addressing a new perspective of credit. Rather than focusing solely on supply-side constraints of credit access, this paper explicitly considers demand-side constraints, such as risk aversion of farmers, financial illiteracy, high transactions costs and lack of access to information on small-scale irrigation technologies. Uptake of credit for the purchase of small-scale irrigation technologies is reduced because of the lack of access to information and knowledge on irrigation technology, and membership in associations conducive to knowledge on irrigation. The study also found that women are more likely to be credit constrained (from both supply and/or demand sides) than men; this confirmed earlier qualitative and fieldwork observations. These findings suggest that policy should focus on addressing both supply- and demand-side credit constraints, including targeted interventions to reduce risks (such as crop insurance) and gender-sensitive policies to ease gender-specific constraints and improve women's access to agricultural credit. *Importantly, policy should pay close attention to improving access to information and capacity development of farmers and farmer associations, as these are crucial to more rapid adoption of improved technologies*.

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

Contributing to the ILSSI research on the structure of the market and role of actors in the market system, IFPRI held regional and national workshops applying the Net-Map method (participatory mapping tool combining social networks, power mapping, stakeholder mapping), in Addis Ababa, Ethiopia (8-9 October 2019) and Accra and Tamale in Ghana (March 9 and 10, 2020). Participants included representatives of government agencies, research agencies, NGOs and the private sector. The general guiding question(s) that framed the participatory activity were: *Who influences the diffusion of improved small-scale irrigation technologies at the national and regional levels?* The results for Ethiopia are published as a discussion paper, "The Diffusion of Small-Scale Irrigation Technologies in Ethiopia: Stakeholder Analysis Using Net-Map"; a companion paper for Ghana is being finalized. The paper that emerged from the activities represented an IFPRI-IWMI collaboration (Bedru Balana, IFPRI & Fitsum Hagos, IWMI).

Ethiopia results show the dominance of government actors in the diffusion of SSI at both national and regional levels, while most private sector and non-governmental actors remain in the periphery. Participants in both workshops highlighted the need for increased financing service to support the adoption of SSI and measures to regulate the quality of equipment. Of note, national and regional meeting participants differed on the level of importance of farmers and regional traders and input suppliers, in diffusion of technologies; regional participants found them more important than national actors. The Ghana national workshop analysis noted that diffusion of small-scale irrigation technologies is considered to be largely influenced by the Ghana Irrigation Development Authority (GIDA) together with private sector actors focused on importation, distribution and financing of technologies. Participants did not consider farmers to have any influence over the process, suggesting a supply-driven process. However, participants in the regional meeting in northern Ghana considered farmers to be key influencers, albeit this was *potential* influence alongside a larger and more diversified set of government stakeholders as regulators and gatekeepers. A key message was that successful irrigation diffusion - from importation to distribution and benefits for smallholder farmers - requires all actors to come together to better understand farmers' needs. A multi-stakeholder platform could help to increase communication between farmers as the ultimate beneficiaries of small-scale irrigation technologies and the many other actors interested in participating in and supporting this process; this platform has also been established by ILSSI in both countries.

Sub-Activity 1.2.4. Stakeholder analysis and mapping of actors in SSI scaling pathway
Researchers and development partners have noted that strengthened linkages within market and food systems can in turn support access to and benefits from improved technologies. Irrigated value chain and equipment supply chain actors, along with other stakeholders that interact in the system, need improved information flows. Toward that end, IWMI designed information checklists and conducted semi-structured and in-depth interviews and focus groups discussions with different actors and stakeholders along irrigated vegetable and fruit agricultural value chains. IWMI leveraged activities under Africa RISING in two districts/regions in Ethiopia. This research highlights that:

- Successful scaling of irrigation technologies requires the bundling irrigation with other agronomic practices and services in commercial agricultural value chains; extension or other supported training on improved water application with irrigation scheduling and best agronomic practices, credit provision, and input and output market linkages.
- Pathways for the scaling of such bundled technologies and services within the irrigated agricultural value chains are taken by existing structures, e.g. input and service providers, local traders and businesses, processors, and markets.
- Local farmer entrepreneur groups, private irrigation service providers, and technicians remain key value chain actors to enhance the reliability of the local irrigation supply (market segment).
- Facilitating local innovation and scaling platforms is sufficient condition for successful value chain-based scaling pathways.

Sub-Activity 1.2.5. Microeconomic study of the effect of loans and tax breaks on the demand for different SSI types
IWMI's micro-economic field study in Ethiopia has been postponed due to Covid19 regulations. IWMI has put the final date for the implementation of the survey as June 2021, which would enable completion of the activity by March 2022. However, inability to implement by that date will require IWMI to reallocate the activity budget.

Sub-Activity 1.2.6. Assess impact of change in cost of water lifting technologies (reduction in tariff) on producer revenue
FARMSIM was used to analyze the potential economic impacts of the tax exemption on household income and nutrition in Ethiopia. The study considered motor and solar pumps with a full tax exemption, which on average reduces by 40% the cost before the tax exemption was approved. It is assumed that the equipment is acquired through a loan/credit (three-year period with an 18% interest rate). We evaluated net present value (NPV), benefit-cost ratio (B/C ratio) and the internal rate of return (IRR). Results of the simulation suggest:

- Removal of tariffs increases the NPV, B/C ratio and IRR, but not *average* profit.
- On average B/C ratios range from 1.5 to 4.2 (greater than the threshold value of 1.0 or break-even) and IRR values range from 0.3 to 1.2 (greater than discount rate of 0.1)
- Amount required to borrow may also decrease with the decline in retail price of equipment and therefore, affect loan access and costs of finance.

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

To facilitate improved linkages across actors and sectors and improve information exchange, build trust, and accelerate equipment market density, ILSSI – led by IWMI – established Small Scale Irrigation multi-stakeholder dialogue processes in Ghana and Ethiopia. Kick-off meetings and a second meeting were held in each country. In Ethiopia, the existing Agricultural Water Management Task Force (AWM-TF) mandate excludes private sector actors and therefore, participants decided the AWM-TF should remain separate from the SSI MSD and private companies, with structured interaction between the MSD and AWM-TF for learning. The in-person workshops to establish the platforms attracted significant engagement from private sector actors. The inclusion of private companies, albeit to varying degree by country, began to establish the presence of private company interests with potential policymakers, a key achievement for both Ghana and Ethiopia where private companies have not been deeply engaged in irrigation equipment supply and services.

Observations from the dialogue process has been published in the paper 'Multi-stakeholder dialogue space on farmer-led irrigation development: An instrument driving systemic change with private sector initiatives' in *Knowledge Management for Development*. This paper highlights that:

- Farmer-led irrigation development multi-stakeholder dialogue space in Ghana fulfils the need for a physical and institutional space to cater for and merge different stakeholder interests.
- The physical space enables private sector actors to envisage their commercial interests, opening up opportunities for collaboration and mobilization of resources.
- The institutional space is a multi-level-playing institution which can trickle systemic change by leveraging the private sector's investments with multi-stakeholders' collaboration, interactive learning, and potential support for commercial scaling of farmer-led irrigation.

While the dialogue platforms had been established in person, the second meeting of the multi-stakeholder dialogues were organized online in August and September. The virtual meetings were organized to keep the interest and momentum, though the virtual modality attracted fewer participants and is likely insufficient to engage all actors in an equitable way, especially value chain actors, such as input suppliers, irrigated produce off-takers and farmer groups. We will explore approaches to future meetings that conform to COVID19 related social distancing.

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

IWMI developed analytical and methodological notes to study marketing margins along the irrigation supply chains in Ethiopia and Ghana. This research responds to concerns over exploitation of farmers and unbalanced negotiating power between suppliers and smallholder farmers; these concerns were raised by the Government of Ethiopia and participants of earlier ILSSI organized workshops. In response, and to deepen understanding of irrigation supply in frontier markets, IWMI researchers have started the scoping analysis and assessment of the upstream of the supply chain. In Ethiopia, products selected for the study include 3 models of Solar Pump, 3 models of motor pump, and 3 models of rope and washer manual pumps. In keeping with COVID19 restrictions, IWMI has initiated phone interviews and written questionnaires, but responses have been limited so additional follow up will be needed. In Ghana, IWMI plans for data collection in FY2021.

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 has identified three business models to pilot SSI scaling alongside ILSSI private sector partners in Ghana and Ethiopia:

- PAYGO asset financed solar pumps with warranty and after-sales technical support (Ethiopia): Clients will be identified (i.e. creditworthiness assessed) with a basic scoring tool that prioritizes water resource and land availability with some consideration of financial information. Proposition: Trust between the company and farmer clients is increased and investment risks reduced for both farmers and the supplier by using PAYGO system and providing marketing support services with less attention to pre-sales screening.
- Off-grid, solar-based post-harvest storage (Ethiopia): Solar powered, off-grid storage installed and offered on PAYGO system in areas with high demand for storing horticultural and dairy products. Proposition: Storage of perishable produces strengthens price negotiation power of smallholder farmers; market linkages between (women and men) farmers and off-takers/traders support reliable, quality produce supply, reduce losses, and increase farmers' incomes.
- PAYGO asset financed solar pumps with warranty and after-sales technical support (Ghana): Clients assessed and finance terms determined through in-depth credit scoring card (developed by CGAP). Equipment supplier offers range of pumps , including higher cost and more powerful solar pumps, to reach more market segments. ILSSI has provided input to strengthen the credit score card in giving women farmers equitable consideration. Proposition: Private sector actor builds market density and large distribution network across multiple value chains, including vegetables, cocoa and soy (proposed); sophisticated scoring card is adequate to screen clients and reduce risk to credit providers.

IWMI is working with PEG Africa to implement the inclusive scaling of farmer-led irrigation, notably:

- Developing a collaboration framework to bridge research and private sector operations
- Customizing solar energy irrigation suitability mapping as an input to PEG Africa’s products and location of distribution and service centers
- Reviewing credit scorecard developed by CGAP and piloted by PEG, recommending changes toward gender equity
- Providing a tool to monitor water abstraction (data sheet provided to PEG)
- Initiating a joint innovation internship between IWMI and PEG Africa

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

An over-reaching activity to analyze big questions related to scaling, IWMI consolidated existing literature, and drafted and tested a holistic framework for a system's analysis to identify systemic barriers to SSI scaling, with a conceptualized systemic approach to open up opportunities for scaling SSI. A draft paper has been developed 'Towards systemic scaling of contemporary farmer-led irrigation development: A conceptual framework'.

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

ILRI mapped stakeholders in the fodder value chain and a publication is under preparation for submission; the paper includes an inventory of actors with roles and responsibilities, strong and weak sides, and interactions between different actors and action points (entry points to nurture the strong sides and strengthen the weak sides). The work was done in two rounds at the project sites, with the first involving conducting inventory of key actors and their contact details. The second round involved inviting representative informants from the different enterprises/institutions for a stakeholder meeting and mapping exercise applied the Netmap tool developed and applied more broadly in irrigation by IFPRI. Preliminary recommendations from "*Analysis of stakeholder roles and relationships in the fodder value chain in Ethiopia*" is outlined in **Annex 3. Preliminary results from fodder value chain analysis**.

In addition to the Net-Map analysis, ILRI completed a fodder market survey based on market surveys in Ethiopia's four main regions: Amhara, Oromia, Southern, and Tigray regions. The survey involved price data recording, feed sampling and interviewing main value chain actors, and was intended to generate a database of feed prices and fodder market potentials for smallholder farmers. The work was conducted in collaboration with national agricultural centers located in the respective regions of the country. Survey households were identified through local extension officers and included feed traders (retailers, wholesalers, processors) and livestock enterprises (buyers). Data were collected from a total of 398 respondents, of which half were feed traders. Analysis of feed samples was completed and after cleaning and decoding, price-quality datasets have been established (https://doi.org/10.18738/T8/BJ0MRQ; https://doi.org/10.18738/T8/YFM43Z). Responses of respondents on feed market operations, networks and constraints were also summarized and a report generated.

Further engagement with stakeholders and cooperatives was deferred due to institutional wide travel restrictions; at the time of reporting, field travel in Ethiopia remains restricted for research data collection and stakeholder engagement.

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

Summary of Progress on Objective 2*: ILSSI continued scientific analysis environmental impact of SSI, and linkages between environmental and human resilience; Applied models to understanding of water quality implications of SSI adoption, based on projected adoption with Ethiopia as the case study; Continued set up for in-depth analysis of climate change and variability, with regard to natural resource and water scarcity; Set up cocoa analysis and engaged with potential users of the research results; Expanded work in Mali with all protocols set up but implementation blocked with COVID; Initiated seed system and irrigated value chain analysis.*

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

Sub-Activity 2.1.2. Irrigation/Water pollution modeling analysis

IFPRI completed the methodology for analyzing water pollution in relation to irrigation expansion, as outlined in Figure 1. This analysis directly builds on and links to the SSI suitability analysis and mapping done previously. The basis is that increased use of irrigation is associated with increased use of agricultural chemicals. The analysis assumes a planning horizon to 2030. The total nitrogen loading in the base year is 198 thousand tons per year. The increased loading due to the addition of 1 million ha irrigated area for fodder, vegetables, and pulses, is 84 thousand tons per year, resulting in total loading values of 282 thousand tons per year. Figure 2 below shows the result projected for 2030 with the realized increased production of irrigated fodder, pulses, and vegetables. National statistics on fertilizer consumption were downscaled to the pixel level to inform the re-construction of agricultural nutrient loading estimates in the base year. Preliminary results have been generated, though authors faced challenges finding a sufficiently large and adequate dataset on the irrigation of vegetables, pulses and irrigated fodder, and efforts continue to collect fertilizer use data at sub-national level. The paper is under development for submission in late 2020.

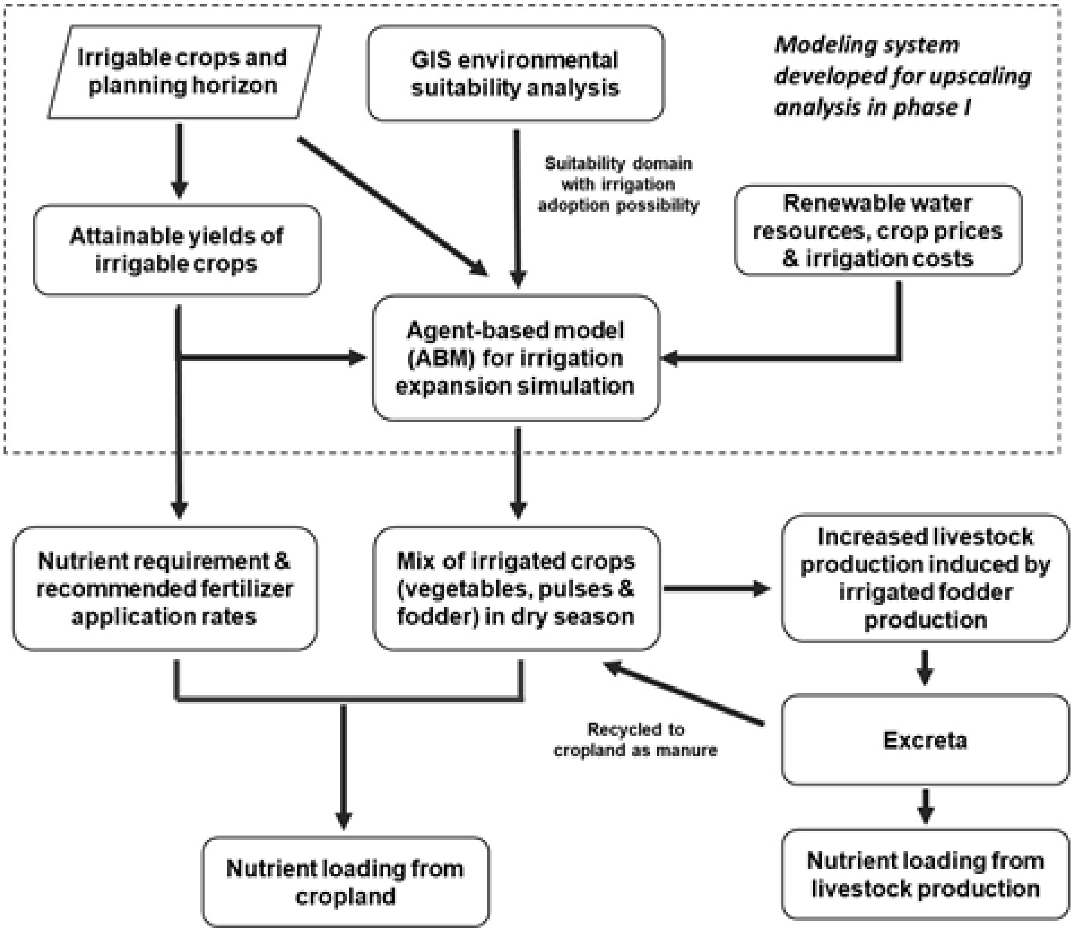

Figure 1. Schematic for analyzing water quality and pollution under conditions of increased irrigation

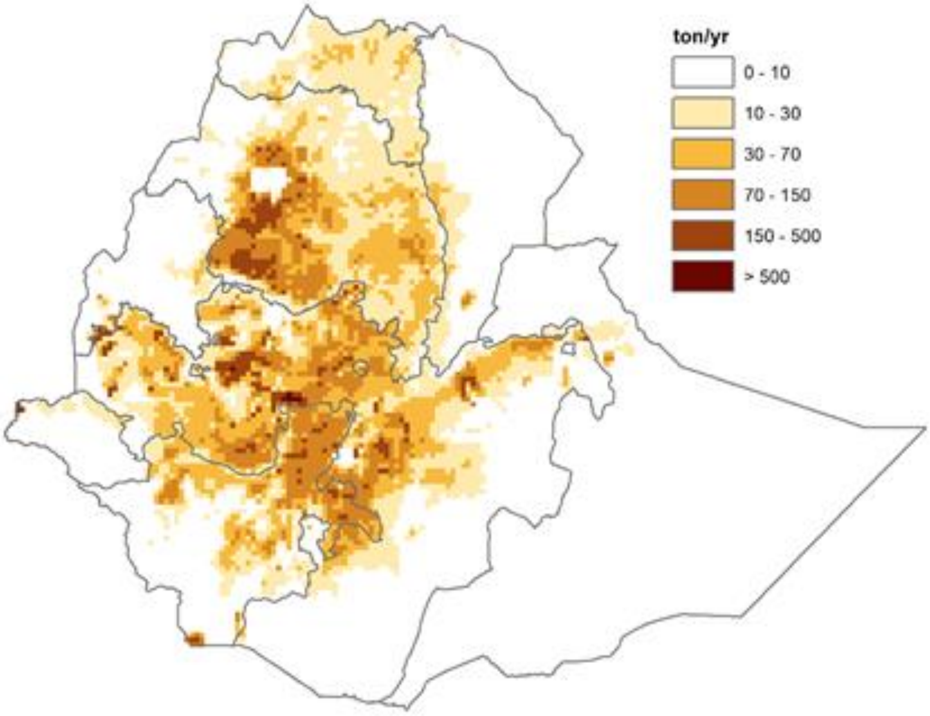

Figure 2. Preliminary analysis on nutrient load in Ethiopia

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

IDSS team set up the methodology integrating several climate model outputs; identified relevant and useable data sources for climate-related analysis. In addition, the IDSS team has worked on bias correction of climate change data; bias-corrected data was generated for the period until 2100 for Ethiopia and Ghana. This has set the foundation for continued analysis of climate change in the project countries**.** The IDSS team estimated climate and weather extreme indices that are used to evaluate future climatic risks and thereby develop strategies to build resilience. The estimated climatic indices include annual total wet-day precipitation, number of days above 1 mm, number of very heavy precipitation days, consecutive dry days, consecutive dry days, summary days, warm spell duration indicator, and cold spell duration indicator (see Annex I for more information). Future climate change extreme analysis for the coming three decades (2021-2050) in Ethiopia showed that:

- Number of rainfall days (rainfall amount > 1mm) may decrease compared to the historical rainfall amount.
- Number of days with very heavy rainfall days (i.e. rainfall >= 20 mm) may decrease in the majority of the studied stations, and models.
- Number of consecutive dry days may increase while the number of consecutive wet days may decrease in all of the studied stations in Ethiopia.
- temperature may get warmer in the comping 30 years (2021-2050) compared to the historical climate (1984-2021); for example, the number of summer days and warm spell duration may increase.
- The decrease in rainfall amount, the number of rainfall days, and the increase in temperature suggest that climate change will impact Ethiopia's agricultural production. Therefore, climate

change adaptation strategies such as small scale irrigation strategies should be implemented to reduce the negative externalities of the climate shocks on the existing agricultural system and build social-ecological resilience.

In addition, ILRI began the preparation of field experiments to screen suitable forage genotypes/cultivars with higher efficiency of water and nutrient levels; Napier and Brachiaria were selected. A PhD student was recruited from Bahir Dar University, and a committee established across ILSSI partner organizations.

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

ILRI developed a study protocol to collect field data related to irrigated fodder and resilience, but COVID19 restrictions have delayed implementation.

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

Sub-Activity 2.2.1: Climate risk assessment

IFPRI continues research on climate risks, with no completed outputs to report to date.

Sub-Activity 2.2.2: ENSO assessment, Ethiopia

IFPRI continues drafting the ENSO assessment paper, with no completed outputs to report to date.

Sub-Activity 2.2.4. Examining how credit and yield-based index insurance can increase resilience

This research aims to identify potential areas where crop insurance could provide a cost-effective risk management strategy in building resilience in Ethiopia. The study has identified areas susceptible to rainfall variability and vulnerable to the risk of crop failure and has simulated historical crop yield distribution using a biophysical model: Agricultural Policy Environmental eXtender (APEX). The result of rainfall analysis (1990 to 2010) indicated that the majority of Regime I, approximately 90% of the area receives more than 750 mm of rainfall throughout the rainfed growing season. In this area, the probability of crop failure due to crop water stress is minimum; therefore, investing in rainfall indexed crop insurance might not be feasible. Instead, supplemental irrigation and infrastructure development such as rainwater harvesting, water storage structures, 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 transferring the risk or managing the risk through crop insurance. The preliminary report of the analysis is found in **Annex 1. Detailed methodological developments and results of the IDSS research.**

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

ILRI established experimental plots for the forage genotype screening, including ten candidate varieties from the forage Genebank. Research equipment for the experiment has been purchased and installed, including a weather station, soil moisture probes, leaf area meter, solar pumps, and irrigation kits. Different levels of fertilizer and irrigation scheduling are being used to screen the forage varieties for water and nutrient use efficiency. Data collection protocols have been developed, and initial soil samples have been collected and analyzed. In addition, three forage demonstration sites (one in the southern region and two in Amhara region) were established by including fourteen forage varieties. The demonstration sites are intended for participatory variety selection on a mother-baby trial approach where individual farmers would be allowed to take one or more of the species demonstrated based on their own criteria and preference. Research assistants and a Ph.D. student have been engaged within the local research areas to ensure that field interventions continue without interruption.

Activity 2.3.: Assess the potential for innovative technology and scheduling tools (f.ex. solar, sensors) to contribute to social-ecological resilience

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

Solar-powered irrigation is considered a climate-smart approach to irrigation development, through linkages to reduced GHG emissions (replacement of fossil fuel technologies) and mitigation tools for climate variability. However, few studies consider matching advice for specific PV solar systems with demands under a changing climate. Given this gap, IFPRI conducted a systematic review of Sizing PV solar systems' methodologies to context and conditions. The study concluded that the current sizing tools, which were widely used to size standalone PV solar systems for *residential* energy supply, have limitations for application to agriculture. Current approaches to determining a PV system size do not reflect climate variability and the associated variability of energy demand for irrigation. To address this gap, IFPRI is considering coupling the PV sizing model with SWAT/APEX in IDSS or other crop models for better irrigation scheduling (meeting crop water requirements at minimum) in the next step of the analysis.

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

IFPRI prepared a methodology and analysis on the climate-risk mitigation potential of solar-powered irrigation, considering changes in temperature and precipitation. ILSSI supported the preparation of the regional analysis of West Africa, while the manuscript and presentation for the whole of Sub-Saharan Africa leveraged other funding. Results on the potential for solar (versus diesel) irrigation in Ethiopia were presented during an energy systems modeling workshop in September [https://www.youtube.com/watch?v=KO6A0KSNRgs&feature=youtu.be] .

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. Collect and analyze household data in Mali

IFPRI developed a Discussion Paper on potential and constraints to small-scale irrigation based on secondary data. Results show that irrigator characteristics demonstrate the commercial orientation of irrigation technology and its relatively higher capital and knowledge intensity compared to rainfed agriculture. In addition, irrigation increases the consumption of nutrient-rich food groups, increases income, and significantly improves household nutrition. The initial desk study offers implications for surveys and future analysis. IFPRI made two field visits to Mali, met with national research partners (notably, Institut d'Economie Rurale), visited small-scale irrigation projects, and consulted with the Malian government. IFPRI also developed the qualitative and quantitative survey protocols, which include the Household Water Insecurity Experiences (HWISE) Scale (coordinated at TAMU), to assess the linkages between agricultural and domestic water insecurities. While IRB approval for the protocol was secured and enumerators trained, COVID19 has delayed the survey; steps are being taken with an in-Mali ethics review to enable implementation.

IFPRI also contributed to the Program of Accompanying Research for Agricultural Innovation (PARI) project, which is led by the Center for Development Research, Bonn University, using the agent-based modeling framework developed under the ILSSI project. The study identified five clusters with a high potential of adoption of small-scale irrigation, including in Sikasso, Koulikoro, Segou, Kayes and Mopti, though also found suitable profits could only be obtained in Sikasso, Koulikoro and Segou.

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

Water scarcity is considered a critical constraint to increased food production in the Sahel, from household to basin level. To better understand water resource availability and provide evidence for water allocation in the region, IWMI is applying Water Accounting (WA) methods and has completed 95% of data acquisition, and cleaning and pre-processing. The process has also been streamlined making use of some latest products for Africa, such as the WaPOR data. IWMI finalized the validation and analysis for key parameters (looking at bias correction, statistical assessments of changes over time), such as precipitation and rainfall. The results have been overlaid with the solar suitability results for Mali, towards identifying the most suitable areas for sustainable expansion. Key findings include:

- Water storage shows a high month to month variability, but the annual change in storage is marginal. This indicates minimal anthropocentric influence.
- Pixel analysis of the surface water balance within Segou and Sikasso reveals that in the identified suitable areas for solar irrigation (with surface water at 0-7 m), water availability ranges from 800 mm to -50 mm/year, depending on the location in the cercle (sub-national unit). This also has implications for sustainable irrigation use.
- Analysis of the shallow groundwater (using GRACE TWS) shows high to medium groundwater availability in the 0-25 m the areas that have been identified as suitable for solar irrigation.

IWMI is currently finalizing its analysis on the implications of the water availability at the annual and seasonal level from the WA+ framework and its correspondence to the suitability results. The final results will suggest potential agricultural value chains that can be supported in specific locations (e.g., seed value chain, vegetable, etc.). The annual and seasonal water accounts are now available. Results were to be shared with decision-makers in Mali, but this is postponed until COVID19 rules allow.

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

Consultations in Mali and West Africa generally highlighted constraints with seed access, prompting ILSSI to begin assessment of potential for irrigated seed production in Mali. Interestingly, the World Vegetable Center's preliminary study shows that access to water is an important constraint to vegetable seed production, as well as the lack of technical capacity in seed production, and post-harvest packaging and storage. Analysis also outlined the complex seed market and regulatory structures with limitations on which actors can play specific roles. Using a system's analysis, the study concludes that the potential of irrigation technologies to contribute to improved water and food security and sustainable resilience can only be realized if other constraints are addressed at the same time; interventions will need to address limitations across the system in a comprehensive manner. Preliminary results can be found in the

Agrilinks event, "Market based Agricultural Technology Scaling in Fragmented Market Settings: Three Cases", as well as the blog, "Tapping into the potential for vegetable seed production in Mali."

The World Vegetable Center completed data collection at the end of August, despite delays related to COVID19, a Coup d'état, and the departure of one key staff member. New staff has been recruited.

Complementary Sub-Activity. Enabling environment analysis toward enhancing the scaling of irrigation and water management technologies

To better understand the possibility of SSI scaling in Mali, IWMI developed a protocol for integrated value chain analysis to carry out a systemic analysis across multiple countries. The characteristics of the (dis/enabling) environment can be categorized into (1) an informal institutional context ("embeddedness environment"), (2) a policy/regulatory framework ("formal institutional context"), and (3) policy implementation ("facilitating services"). Eight participants from six African countries (Burkina Faso, Mali, Nigeria, Sudan, Ghana, Ethiopia) were trained in Ethiopia in March in collaboration with the TAAT-AfDB funded project. The trained participants will use the protocol co-developed under ILSSI to systemically analyze the enabling environment for scaling of irrigation and water management technologies.

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

Summary of Progress on Objective 3*: Balancing the rapid scaling of irrigation with equity and reduced negative social impacts is a priority of ILSSI's work and the focus of Objective 3. As ILSSI began working with private companies, we recognized that companies generally do not have an operationalizable social equity plan, even those that claim a gender-equitable mission. Rather, companies and some development partners segment market by income without consideration of gender. As it is clear that investments must be targeted to reach women and resource-poor farmers, ILSSI consolidated its workplan to provide applicable evidence to development investors and companies, as well as supporting tools. In addition, attention to farmer-led irrigation continues to increase, and both development investors and companies seek to catalyze and speed up commercialization amid an absence of governance structures for local water resources. ILSSI has prepared the protocols to analyze governance issues and pilots' local level approaches. The work under Objective 3 is particularly impacted by COVID19, and many of these sub-activities will only be implemented once it is deemed safe by national agencies in project countries.*

Activity 3.1: Institutional and policy analysis & strengthening of governance

Sub-Activity 3.1.1. Design and pilot governance studies using different methods, including experiential learning

IFPRI undertook scoping studies in Ethiopia and did preliminary site selection in Ghana (cut short due to COVID19), and also refined the game design to adapt to the local context. Protocols, questionnaires, and surveys have been developed, and the sample design has been finalized. Moreover, local collaborators have been hired. IFPRI also initiated the ethics review process and are in contact with Addis Ababa University for local ethics review. The identified areas for the pilots in Ethiopia include Butajira – Enseno in Southern Nations, Nationalities, and People's Region (SNNPR) at the upper part of the Meki River catchment and includes Meskan, East Meskan, West Sodo, Sodo, and Marko districts surrounding Butajira town. The fieldwork plans for Ethiopia continue to be adjusted, while Ghana remains delayed but may be initiated without direct IFPRI involvement. IWMI has been a collaborated on this activity through input on sites and scoping visits.

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

Sub-Activity. 3.2.2. Gender and inclusivity (emphasis on the private sector and business models)

This activity analyses inclusive/exclusive mechanisms for women's effective engagement in and gains from smallholder irrigate agricultural value chains to understand how and when marginalized female farmers (reflecting social inclusion) are engaging in or could engage with the scaling of small scale irrigation (reflecting innovation aspect) along the agricultural value chain (reflecting contextual system). A qualitative study has been conducted and an analytical framework prepared based on power dynamics, perspectives combining livelihood asset and access, and value chain approach to better understand the role of community- and household-based factors and their interactions in shaping inclusion/exclusion. IWMI will collect further data when allowed.

TAMU and IWMI have also provided guidance for PEG Africa related to increasing access for women farmers to PEG's solar irrigation pump products. Lessons from PEG Africa will be shared with other irrigation equipment suppliers, including the ILSSI partner in Ethiopia. Eventually, broader stakeholder groups are involved in small scale irrigation dialogue platforms. At present, the PEG financial scorecard that will determine credit worthiness of clients [developed by CGAP] does not include any criteria that particularly target women, and PEG does not have a strategy to target women as a market segment. ILSSI partners have provided PEG input to address gender inclusion, including:

- Proposed added credit scorecard, including qualitative criteria
- Recommended added product and service preferences of women
- Recommended contractual features should be tailored to two groups of women: 1) Individual woman who cannot currently afford PEG products but with the potential to do so in the future, and 2) Groups of women who have the potential to afford PEG products when they pool resources.

Sub-Activity 3.2.3. Gendered irrigated fodder value chain analysis

Women play a strong role in organizing and managing fodder markets, which points to the potential for women to benefit from irrigated fodder development, but only if approached with the intent to support equity. In order to design future interventions to have equitable outcomes, however, a clear understanding of current conditions is needed. Toward that end, ILRI has designed a study protocol and instruments for in-depth documentation and analysis of gender roles and relations in fodder value chains and in irrigated fodder production and decision-making. The tool has been jointly developed by a gender specialist at ILRI, and with IFPRI and TAMU, to include economic, environmental and women empowerment indicators for wider analysis. The protocol has been submitted for ethical review, with data collection expected to commence once COVID19 regulations allow in Ethiopia.

During the reporting period, ILRI identified fodder and dairy cooperatives led by and constituted by women and put in place sub-award mechanisms to engage women's cooperatives in irrigated fodder production and the use of irrigated fodder in dairy chains. The award mechanisms are milestone performance-based, which is a new model of partnership for ILRI that required higher-level approvals within the institution. With the new partnerships and the instruments prepared, implementation of activities will begin once COVID19 regulations in Ethiopia allow.

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

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

Agricultural water and WASH are often separated in investments and development interventions, but earlier ILSSI research, as well as other studies, show that households manage water across and for multiple uses. In addition, earlier ILSSI studies on nutrition highlight that water access as a pathway to improved nutrition. To explore further, IFPRI used data collected under ILSSI to examine the role of irrigation in improving outcomes for water supply, hygiene, and sanitation (WASH) with potential further nutrition benefits in Ethiopia. The study finds that the source of water matters: groundwater irrigators are most likely to also use that source for domestic purposes. These households also spend the least amount of time fetching water. At the same time, non-irritating households are more likely to have insufficient water for domestic purposes. In terms of the WASH environment, households that use surface water for both irrigation and domestic uses fare worst. They are least likely to have a handwashing station, report the lowest handwashing rates, and are least likely to wash hands before feeding children. Improving access to domestic water through irrigation development is only effective if the water is of sufficiently high quality. While these are important findings for future water investments, the survey data did not lend itself to direct analysis of Water Supply, Sanitation, and Hygiene.

Complementary Sub-Activity. Integrating nutrition into irrigated fodder value chain analysis

Nutritional status indicators were included in the gender study tool for the irrigated fodder value chain analysis, under a collaboration between ILRI and IFPRI. The aim is to generate data to explore the impacts of irrigated fodder production to the nutrition and health of farm households. This will be complementary to the IDSS analysis of irrigated fodder, particularly the FARMSIM results (See Annex 1, Section on **Yield-based crop insurance methodological approach and scenario analysis**).

3. Objective 4 - Achieve impact through uptake of ILSSI research results and/or methods (Human and Institutional Capacity Development; Stakeholder Engagement; Outreach and Communications)

Summary of Progress on Objective 4*: Despite COVID19, ILSSI continued to try to positively influence development investments. Communications and outreach efforts were strengthened on-line with a revamped ILSSI website, newly created quarterly newsletter, and intensified social media sharing. ILSSI researchers have also been invited to share research results in a number of global forums relevant to water and agriculture. However, COVID19 restrictions on travel as of March 2020 led to the cancellation of in-person meetings and training. HICD events declined compared to previous years. Virtual trainings have not been as effective as in-person, and we noted lower participation in virtual events. Some countries began to allow trainings in small and socially distanced groups toward the end of the fiscal year. Student engagement was also hindered, as TAMU could not process visas for students and scholars expected to visit the US.*

Activity 4.2. Short-Term and Long-Term Training on subject matter (SSI technology and practices, gender, nutrition, irrigated fodder, etc.)

Sub-Activity 4.2.4. Trainings targeted at producers, technical experts and other local and national stakeholders; trainings targeted at the private sector

While USAID is no longer counting short-term trainees, ILSSI has continued to collect data on trainees to monitor short-term training activities over the life of the project. A list of trainings and trainee data is found in Table 1 below. The IDSS team postponed 3 planned short-term trainings that had been scheduled in Ivory Coast and Ethiopia (including at least one under the Farmer to Farmer project); the trainings will be carried out when travel is allowed or will be redesigned using a virtual format.

Table 1. Summary of short-term training

Country of Training	**Brief Purpose of Training**	**Who was Trained**	**Number Trained**		
			M	**F**	**Ttl**
Ghana (regional)	Integrated decision support system (IDSS) methods/models (February 17th – 21st, 2020) Trainee country: Ghana, Benin, Burkina Faso, Côte d'Ivoire, Gambia, Niger, Nigeria, Senegal, Togo	Researchers; Civil servants	42	25	67
Ghana	Training of PhD student Afua Atuobi-Yeboah of University of Ghana at Legon in netmap workshop facilitation and data analysis	Researcher	0	2	2
Mali	Enumerator training on data collection methods (February 3rd –5th, 2020)	Researchers and students	29	11	40
Ethiopia (regional)	Enabling environment analysis toward enhancing the scaling of small-scale irrigation and sustainable agricultural water management	Technical experts; Researchers	6	2	8
Ethiopia (regional)	Scaling of Small-Scale Irrigation: Gender inclusion and innovation (March 5th – 6th, 2020)	Researchers and students	29	10	39
Ethiopia	Solar pump operation for irrigated fodder	Producers	10		10
Ethiopia	Fodder chopper demonstration and operation training (February 6th –8th, 2020)	Producers	31	0	31
Ethiopia	Irrigated fodder services (February 8th, 2020)	Entrepreneurs	14	0	14
	Total		**161**	**50**	**211**

Private sector short-term trainings

ILSSI's private sector partner PEG Africa includes reporting on short-term training in its performance-based sub-award. Since July 2020, PEG Africa conducted skills-development training for four (4) new and three (3) existing technicians to enhance their knowledge of solar pump irrigation technologies. New technicians developed hands-on skills in installing a solar water pump, while existing TSRs enhanced their knowledge and skills-set in various functionalities and aspects of the technology, such as panel configuration. In addition, the farmers who purchased pumps through the ADVANCE II project (being 5 in total) during the period under review also had either themselves or their employees trained in the operation of solar pumps. Furthermore, PEG Africa has partnered with and provided technical training to two Agricultural Engineers of the Ministry of Food and Agriculture in the Western and Bono Regions where farmers are purchasing solar irrigation technologies; this is to enhance the ability of the civil service to backstop farmer maintenance and use of solar pumps.

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

ILSSI was unable to meet the planned number of graduate students and post-doctoral research fellows engaged, as COVID19 restricted the movement of students and, therefore, the recruitment process. The long-term trainees that have been engaged and are being supported by ILSSI are listed in Table 2 below.

Table 2. Summary of Long-Term Training

University	Degree	Program End Date (mo./year)	Degree Granted (Y/N)	Home Country
University of Hohenheim	PhD	12/31/2020	N	Germany
Bahir Dar University	PhD	01/16/23	N	Ethiopia
Texas A & M	PhD	08/12/2023	N	USA
Texas A & M	MSc	05/12/2022	N	USA
Texas A & M	Post-doctoral fellow	08/2023	N	Ghana

Sub-Activity 4.2.7. Innovation scholarships (research on scaling)

Toward new approaches to encourage innovation of youth and to strengthen the linkages between the academic and private sectors, IMWI developed 'innovation scholarship' as 'best-fit' for capacity development approaches to the scaling of small-scale irrigation innovation. The 'best-fit' approach is characterized by four dimensions:

- Demand-driven capacity: Initial capacity needs related to SSI scaling include lack of technical expertise at multiple levels in technologies, lack of linkages between education, research and private sector/market actors in the sub-sector, and research institutions and organizations

unable to respond to knowledge needs in sub-sector. These will be further identified along with the SSI scaling pathway.
- Multiple levels: Capacity development is at and with individual, organizational, institutional, and system levels.
- Agile process: Capacity development is a continuous process of identifying capacity gaps along with the SSI scaling pathway, building individual and organizational capacity through innovation grant, and strengthening institutional and system capacity with facilitating dialogues and interactive learning amongst stakeholders cross sectors to build trust, share knowledge and foster collaboration.
- Dynamic enabling environment: encompasses context-specific elements such as people, value chains, markets, financing mechanisms, policies and regulations, professional knowledge, power relations, incentives, history that influence the capacity development processes as well as the capacities that are needed.

Following from the HICD concept on fostering innovation and cross-sectoral linkage, IWMI organized a seminar on ‘Scaling of Small Scale Irrigation: Sharing Research from ILSSI project Phase II’ assembling 40 participants – students and faculties – from Bahir Dar University. In this seminar, participants exchanged (1) research in innovation scaling and gender inclusion developed within ILSSI, and (2) insights of using qualitative research design and method for innovation scaling and gender inclusion study. Interests in research collaboration and innovation scholarships were explored, highlighting two research areas for the collaboration, including:

- Economical, institutional, and governance aspects of SSI, and
- Gender analysis, approaches and implication of SSI Technologies along the value chain.

IWMI signed a three-year agreement with Bahir Dar University to implement the innovation grant activity, starting 1st July 2020. The agreement is built around four major objectives:

- Assess private sector actors’ research and knowledge needs in relation to small scale irrigation scaling in Ethiopia;
- Organize Hackathons to develop innovations toward addressing the needs of private sector;
- Identify and co-supervise, with the private sector, graduate students to carry address identified research needs;
- Identify suitable recently graduated BSc. and MSc. students to carry out an internship with the private sector partner; and
- Manage the innovation scholarships within BDU’s Innovation Hub.

In Ghana, the innovation scholarship takes a 'competitive pitching' approach to identify young entrepreneurs, innovators, and recent graduates with bachelor’s and master’s degrees to develop innovations and/or carry out demand-based research to address the needs of the private sector. IWMI, in collaboration with PEG Africa and other national partners, will organize Innovation Grant (InGrant) Pitching Contests, selecting interns that:

- create and foster national research-private sector partnerships to mobilize innovation

- catalyze contextually relevant local technical, social and financial innovations to support scaling of small-scale irrigation and increase access to and adoption of small-scale irrigation, and
- support the next generation of entrepreneurs and young professionals through private sector work experience.

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

- Multi-stakeholder dialogue, Ghana, October 2019
- Multi-stakeholder dialogue, Ethiopia, March 2020
- Private Sector Consultations, February (Ghana) and March (Ethiopia) 2020
- IFPRI gender and nutrition presentations (Ethiopia, Ghana)
- Multi-stakeholder dialogue, Ghana, August 2020
- Multi-stakeholder dialogue, Ethiopia, September 2020

Sub-activity 4.3.4. Regional and global events, platforms/dialogues, and other convenings (present, share, and receive input on research results/evidence)

- ILSSI research formed part of the Farmer-led Irrigation Development (FLI) – Webinar Series (2 sessions) organized by the International Water Management Institute (IWMI), Water Global Practice (GP) of the World Bank, Daugherty Water for Food Global Institute (DWFI) and the Global Water Partnership: https://www.iwmi.cgiar.org/events/farmer-led-irrigation-development-fli-webinar-series/
- ILSSI research contributed to the virtual World Water Week event on ‘Operationalizing farmer-led irrigation: Implementers Dialogue’: https://www.worldwaterweek.org/event/9181-how-to-operationalize-farmer-led-irrigation-implementers-dialogue
- ILSSI research was presented within the Tropentag conference keynote address (Petra Schmitter) on ‘Food and nutrition security and its resilience to global crisis’ – on the crucial role of water and irrigation in enhancing food and nutrition security’: https://www.youtube.com/watch?v=WI5is6_KSTg#action=share

Activity 4.4. Outreach and communications

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

- **Website**: 10,500 page views have been recorded for the ILSSI website during this period (although no data available between October 1 through December 1, 2019, at which point ILSSI migrated to a new website). ILSSI migrated and revamped the website in December 2019.
- **Social media presence**: On social media, tweets from the ILSSI profile gained more than 121,000 impressions, and Facebook posts reached more than 6,000 readers during this period.
- **Newsletter**: The new ILSSI newsletter published its first issue in December 2019 (open rate 61.10%, click rate 19.40%), a second issue on the occasion of World Water Day in March 2020 (open rate 49.30%, click rate 18.50%), and a third on the role of the private sector (open rate 50.3%, click rate 16.4%). The newsletter currently has 182 subscribers.
- **News stories**: 24 news stories were produced and published on the ILSSI website, including on how irrigation helps Ethiopian women make more of milk and other dairy products, how

scientists and entrepreneurs battle climate change and water scarcity in the Ethiopian Highlands and how solar-powered irrigation could boost climate resilience for millions. Four posts in a series of student interviews have also been featured, showcasing the capacity development efforts ILSSI is undertaking. The program has also contributed input and stories to other platforms, including Agrilinks.org, Feed the Future, and Farmers Review Africa.

- **Briefs**: ILSSI has produced three new briefs summarizing program findings on water resources, economic growth and nutrition. ILSSI partners have also published multiple technical briefs based on research from ILSSI.
- **Webinars**: ILSSI has contributed to numerous webinars, recognizing this as a feasible and suitable engagement strategy during the COVID-19 pandemic; webinars with ILSSI contributions have been focused on farmer-led irrigation (hosted by the International Water Management Institute (IWMI)); on market-based agricultural technology scaling (organized by Agrilinks.org); on water security as key to ending hunger (organized by the African Ministers' Council on Water (AMCOW)); and more.

Sub-Activity 4.4.7. Scientific conferences and invited scientific presentations

ILSSI contributed to in-person conferences and virtual conferences, while several accepted presentations were canceled due to COVID19. A list of conference papers and presentations is in the publications list in **Annex 2. Data and publications**. A few highlights include:

- ILSSI co-convened with the Global Good Initiative/Intellectual Ventures a session on 'Advances in African Hydrology and Climatology: Observations, Modelling, and Sustainable Water Management'. American Geophysical Union (AGU) Meeting, December 2019 in San Francisco, California.
- IFPRI, "Last Mile Energy Access for Productive Energy Use in Agriculture in Sub-Saharan Africa – What and Where is the Potential?" at the American Geophysical Union Meeting, December 2019 in San Francisco, California.
- 'Dynamics of small scale irrigation development: Subsidizing and capitalizing pathway of scaling' presented at the 2nd International conference on 'Irrigation and Agricultural Development, from 25th to 27th February 2020 at University for Development Studies (UDS) in Tamale, Ghana.
- Multiple papers presented during the virtual Livestock Systems Innovation Lab conference.

Sub-Activity 4.4.8. Publications and data

ILSSI continued to see strong collaboration across research partner institutions on publications and outreach. Under COVID19 restrictions that prevented fieldwork and local data collection, research partners shared datasets and contacts for phone surveys in Ethiopia and Ghana. The restrictions on traveled to more desk studies and analysis of existing data sets, as well as some shift to telephone-based interviews.

ILSSI also made progress toward establishing a long-term repository of all publications on the TAMU library through Oaktrust. This will help to ensure that there is continued access to reports and project-specific technical papers, as well as links to journal publications after ILSSI closes as a project.

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 2. Data and publications**.

Table 3. ILSSI Publications (October 1, 2019 – September 30, 2020)

Category of publication and/or knowledge product	**The total number across the project (i.e. all research partners)**
Peer-reviewed publication	18
Discussion/Working paper	4
Technical report	2
Conference paper, poster, or presentation	11
Outreach and social media (e.g., blogs)	3
Capacity development material or product	0
Submitted and under review, and/or accepted with revisions	17

4. Technology transfer and scaling partnerships

Application and/or transfer of analytical methods developed under ILSSI

IFPRI reported the use of the agent-based modeling framework developed under the ILSSI project, as a contribution to the Program of Accompanying Research for Agricultural Innovation (PARI). PARI brings together partners from Africa, India and Germany to develop innovative approaches that support sustainability of agricultural growth, as well as food and nutritional security, in Africa and India; the program is part of the One World – No Hunger Initiative supported by the German Government.

In addition, the research team at Texas A & M is applying the IDSS methodology to irrigation, climate variability and COVID19 responses in Nepal, under the sub-award from CIMMYT for the CSISA activity.

Use of ILSSI research for scaling irrigation solutions

The scaling of irrigated fodder cultivation practices continues to expand, in collaboration with the district extension and research centers of Ethiopia. A total of 338 new farm households adopted fodder cultivation on approximately 6 ha of land in total. Forage planting materials were sourced from the ILRI forage Genebank and Andassa research center. In addition, three dairy cooperatives were selected as sub-awardees of ILRI to establish a local forage seed system and strengthen the fodder value chain; this deepens linkages with local public agencies and increases knowledge sharing. Success Stories from the irrigated fodder research and outreach can be found in **Annex 4. Success stories.**

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

Solar for Agriculture Resilience (SoLAR) Project, Inception Workshop, January 2020. ILSSI's systemic innovation scaling approach was presented and discussed with 40 participants (researchers, representatives from the Swiss Agency for Development and Cooperation, other stakeholders) from

Nepal, Pakistan, Bangladesh, Sri Lanka, and India. The systemic innovation scaling approach encompasses of processes of identifying what works, what fits, what is responsible to the systemic barriers and continuing with what works, fits and those responsible through partnering with the private sector and other actors to pilot inclusive scaling of small scale irrigation and facilitating multi-stakeholder dialogues to foster the interactive learning.

ILSSI completed a joint initiative with the Global Good/Intellectual Ventures organization, which assembled a technical panel to advise on future investments in financial smallholder irrigation. The efforts were funded by the Bill and Melinda Gates Foundation. The emphasis of the work was on identifying ICT tools, methods, and apps that can catalyze access to finance for SSI. Through the initiative, over 20 projects related to SSI were documented, as reported in the workshop documentation. The Technical Advisory Panel held a virtual workshop to synthesize case study and survey information and identify gaps and high potential areas for development investments in technologies to increase access to finance. Some of the cases and information have been subsequently shared with the World Bank for the guidebook on FLI, as well as presented at two ILSSI SSI Dialogue Platform meetings to share lessons with stakeholders in Ghana and Ethiopia. The results have been reported to the Bill and Melinda Gates Foundation to consider in future investments in agriculture, finance, and technology development.

ILSSI has provided contributions from ILSSI to a guidebook on Farmer Led Irrigation for future World Bank investments in small scale irrigation, primarily focused on SSA. This followed from informal consultation and contribution to country-level project design. The guidebook is expected to be published in the next reporting period.

In addition, ILSSI researchers at IFPRI, IWMI and TAMU participate in the Global Framework on Water Scarcity in Agriculture (WASAG), particularly the WASAG Working Group on Water & Nutrition. IFPRI-led research under ILSSI has been shared with multiple meetings and public events (such as World Water Week) that examines the linkages between irrigation and nutrition, and broader health implications for irrigators compared to non-irrigators. The work also touches on multiple uses and gender equality. WASAG's Working Group on Water & Nutrition includes global actors, such as the U.N. Food and Agriculture Organization, which can influence the design of future investments in irrigation.

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

Throughout the first two quarters of the fiscal year, ILSSI was on track for completing nearly all tasks according to the workplan schedule. However, ILSSI partners face delays in project countries due to COVID19 restrictions. Researchers have adapted activities where possible to virtual platforms, but in-person data collection and engagement are delayed. Where possible, ILSSI partners have obtained guidance and are proceeding to obtain Institutional Review Board approval to implement in-country research activities that comply with local social distancing rules. The restrictions have also impacted the plans for innovation scholarships and internships and on-boarding of long-term trainees at Texas A & M in College Station, Texas. The delay relative to the targeted schedule will be assessed once travel restrictions are lifted; some activities may be redesigned or resources reallocated to other sub-activities.

Another critical concern is the sub-awards to the private sector partners, in particular, the partner in Ethiopia. While Rensys Engineering executed the sub-award with TAMU to undertake activities in July

2020, the company lost key personnel and has delayed in submitting the 'accelerator' milestones that were intended to kick start the business and marketing plans. The sub-awardee has received additional support and an extension, recognizing the challenges of the private sector and COVID19 in Ethiopia. However, ILSSI ME is monitoring the company closely to determine risks to performance and will take action to address non-performance, as needed.

6. Future work

In the next fiscal year, the ILSSI ME will emphasize collaboration across partners and expanded linkages with regional and global networks that influence development investment. In addition, the ME will continue to build on linkages with other programs and projects funded by USAID, including those supported by USAID Missions in Feed the Future target countries. As the project enters the eighth year of research, ILSSI will revise impact pathways and expand outreach toward achieving impact after project exit.

Moreover, as countries and institutions begin to adapt and allow for in-person engagement and fieldwork that complies with social distancing, ILSSI anticipates that partners will return to limited data collection in the field. Most activities are collaborative with specific partners leading activities, including:

ILRI: Field level project activities will be implemented, including gender analysis along the fodder value chain, cost-benefits of irrigated fodder, the establishment of community-based fodder seed multiplication, generating data on forage variety screening, demonstration of different small scale irrigation technologies, and engagements with the private sector and the local extension on scaling activities.

IFPRI: A focus on re-engaging in Mali's fieldwork and starting the groundwater governance scoping work in Ethiopia. Additionally, publishing a series of research articles that had been developed as working papers or as drafts. The continued analysis will be conducted on the impact of small-scale irrigation to combat the ENSO impacts in Ethiopia and changes of women's time use with and without irrigation. IFPRI will commence analysis on the PSNP in Ethiopia, under collaboration with the IDSS team at TAMU, and supported through buy-in from the BHA.

IWMI: IWMI expects to proceed with scaling research, including engaging with the private sector at different levels and innovation scholarships and internships. IWMI will also conclude the Water Accounting resource analysis in Mali and working with the World Vegetable Center in Mali on irrigation guidance and training. IWMI will also continue to lead the dialogue platforms in Ghana and Ethiopia, creating linkages that can facilitate scaling and innovation.

World Vegetable Center: WorldVeg expects to complete two reports and provide detailed information on the vegetable seed sector in Mali while identifying entry points for strengthening the sector with IWMI. WorldVeg also intends to generate capacity development materials for trainings.

IDSS team at Texas A & M: The IDSS team scope of work is expanding with assessments on land and water resources related to irrigation in Mali and Nepal and continued assessments related to climate variability in West Africa, including related to the cocoa sector. IDSS will also begin assessments on the PSNP in Ethiopia.

Gender and Policy research at TAMU: Through the ME and the Geography Department at TAMU, and in association with the HWISE network, ILSSI will continue to carry out policy-related research on small scale irrigation across Sub-Saharan Africa, expand on research and outreach around gendered implications of SSI and farmer-led irrigation expansion, and deepen research and data collection on multiple uses of water in water-scarce areas of Sub Sahelian Africa.

Annex 1. Detailed methodological developments and results of the IDSS research

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

Sub-Activity 1.1.6.b. Develop irrigated fodder suitability map (Identifying irrigated fodder production areas considering livestock density, feed preference and supply scenarios; biomass national fodder production potential)

Background

Livestock is an integral part of the agricultural system in Ethiopia. It accounts for about 40% of the economy and provides employment to more than 30% of the agricultural labor force (Asresie and Zemedu, 2015). The livestock sector serves as a source of food, power for farming, and transportation. Ethiopia has the largest livestock population in Africa. However, shortage of feed, seasonality, feed quality and quantity, and lack of access to basic veterinary services are major constraints affecting the livestock production system (Ahmed et al., 2016; Tonamo, 2016). Since livestock constitutes a large part of smallholders' livelihoods, developing a better feed and fodder production system would contribute to poverty reduction and social-ecological resilience by improving livestock productivity through addressing bottlenecks in the quantity and quality of feed. The Innovation Lab for Small Scale Irrigation has identified suitable sites for fodder production in Ethiopia using promising small-scale irrigation practices that could improve productivity, environmental sustainability, household income, and nutrition. The fodder crops studied include Napier (Pennisetum purpureum), alfalfa (Medicago sativa), oats (Avena sativa), vetch (Vicia sativa), desho (Pennisetum pedicellatum). The study also evaluates the irrigation potential of groundwater using simple water-lifting technologies.

Assessing suitable land for fodder production

The potential land suitable for sustainable fodder production across the country was identified using a GIS-based Multi-Criteria Evaluation (MCE) technique. In MCE, the major factors affecting the suitability of the land for fodder production were mapped, weighted, reclassified, and overlaid to develop a single-index fodder suitability map. The biophysical factors considered include climate (temperature, rainfall, and potential evaporation), soil (soil texture, pH, and soil depth), land use, and slope. The socio-economic factors included were access to market and feed demand. The access to the market was represented with proximity to paved roads, and livestock feed demand was represented with livestock density applying the concept of Tropical Livestock Unit (TLU) (Hiernaux et al., 1997). The fodder suitability analysis was done for a specific crop by incorporating crop characteristics reported under the FAO-EcoCrop database (Ecocrop, 2000) to determine the main niche for optimal fodder production sites. The fodder types were selected by the International Livestock Research Institute (ILRI) together with local stakeholder engagement. The selected fodder crops include Napier (*Pennisetum purpureum*), alfalfa (*Medicago sativa*), oats (*Avena sativa*), vetch (*Vicia sativa*), desho (*Pennisetum pedicellatum*). The crop characteristics extracted from FAO-EcoCrop database, includes the range of temperature, soil pH, and soil depth required for optimal and absolute growth. The weighting of factors was determined by applying a pair-wise comparison matrix (Saaty, 1977). The general methodology framework of fodder production suitability analysis, input data source, and their respective spatial resolution are presented in Figure 1and Table 1.

The groundwater data from the British Geological Survey (BGS) was used to evaluate the irrigation potential of the groundwater using simple water-lifting technologies such as pulley and bucket, rope and washer pump, and solar pump. In a previous study, the BGS depth to groundwater and potential borehole yield were compared with observed groundwater yield data in the central part of Ethiopia, and the result indicated a reasonable performance of the BGS data in capturing the observed potential borehole yield (Worqlul et al., 2017). The BGS's depth to groundwater and potential borehole yield data were overlaid on the potential suitable land to evaluate the accessibility and potential of the groundwater to cultivate fodder.

Table 1. Source and spatial resolution of input data for the fodder suitability analysis.

Data	Source	Spatial resolution (m)
Land-use	Global Land Cover Datasets, 2010	30
Soil	Africa Soil Information Service, 2015	250
Soil pH	Africa Soil Information Service, 2015	250
Soil depth	Africa Soil Information Service, 2015	250
Digital Elevation Model (DEM)	Enhanced Shuttle Land Elevation Data from the United States Geological Survey, 2000 released in 2015	30
Road network	Digital Chart of the World, 2006	--
MODIS potential evaporation (mm)	MOD16 Global Terrestrial Evapotranspiration Data Set (2000 – 2010)	1,000
Rainfall (mm/year)	Ethiopian National Meteorological Agency (ENMA) from 2000 to 2010	--
Fodder crop characteristics	FAO-EcoCrop database	--
Livestock population density	Ethiopian Central Statistical Agency	--
Potential borehole yield (l/s)	British Geological Survey, 2012	5000
Groundwater storage (mm)	British Geological Survey, 2012	5000
Groundwater depth (m)	British Geological Survey, 2012	5000

Groundwater data from the British Geological Survey (BGS) was used to evaluate the irrigation potential of the groundwater using simple water-lifting technologies such as pulley and bucket, rope and washer pump, and solar pump. In a previous study, the BGS depth to groundwater and potential borehole yield were compared to observed groundwater yield data in the central part of Ethiopia, and the result indicated a reasonable performance in capturing the observed potential borehole yield (Worqlul et al., 2017). The BGS's depth-to-groundwater and potential borehole yield data were overlaid to evaluate accessibility and potential borehole yield of the groundwater to cultivate fodder in the most suitable land. Data on crop characteristics such as absolute and optimal growing temperature, soil pH, and depth conditions were obtained from Ecocrop (2000) and FAO (2011) and are presented in Table 2.

Table 2. Characteristics of selected fodder crops considered to estimate the potential production area in Ethiopia (Ecocrop, 2000; FAO, 2011).

Fodder	Optimal temperature (°C)	Absolute temperature (°C)	Optimal soil PH	Optimal soil depth (cm)
Napier	25 - 40	15 - 25 & 40 - 45	5.0 - 6.5	> 150
Alfalfa	21 - 27	5 - 21 & 27 - 35	6.5 - 7.5	> 150
Vetch	16 - 21	8 - 16 & 21 - 35	6.0 – 7.0	>100
Oats	16 - 21	5 - 16 & 21 - 26	5.0 - 7.0	>50
Desho	20 - 25	15 - 20 & 25 - 35	5.5 – 7.0	50 - 150

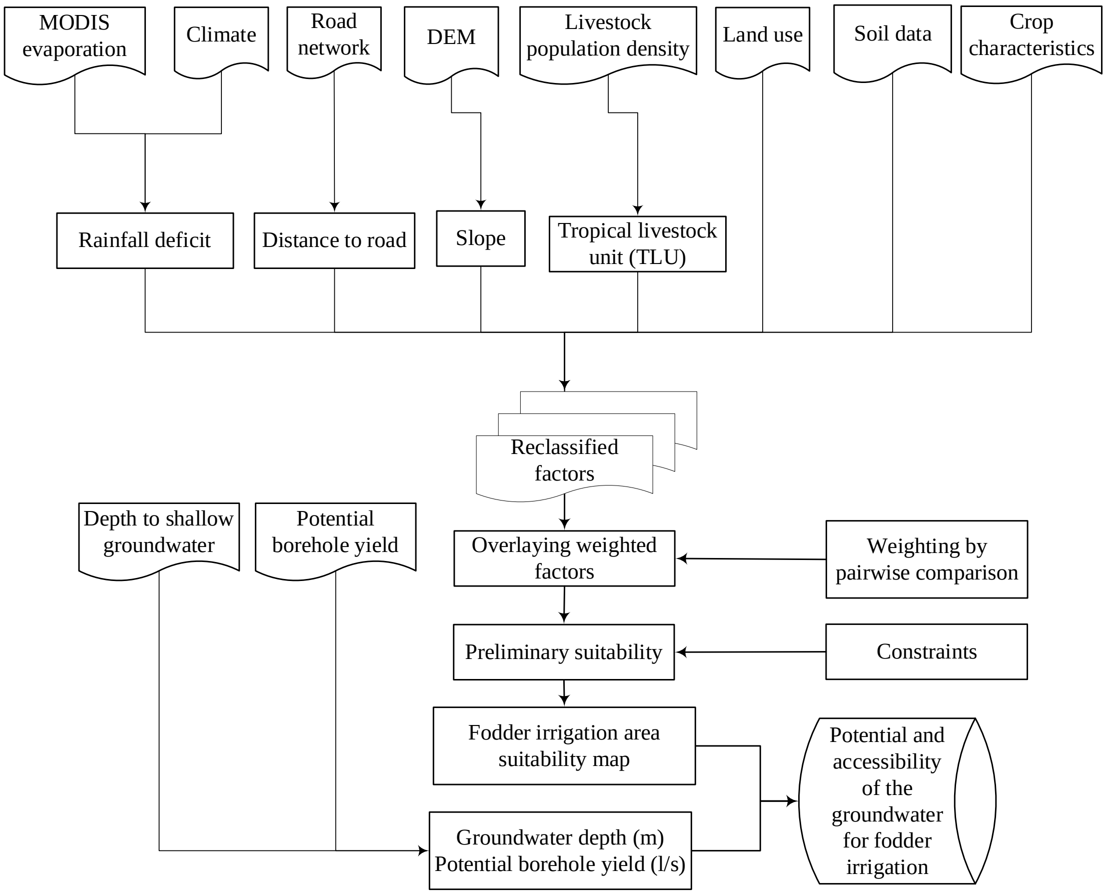

Figure 1. Schematic diagram of potential fodder production suitable area mapping and groundwater potential.

Biophysical modeling to estimate fodder biomass production and water resources availability

The SWAT model was developed, calibrated and validated to estimate fodder biomass production and availability of water resources across the entire Ethiopia (Dile et al., 2020).

The SWAT model's crop growth algorithm was used to estimate the biomass yield for vetch fodder crop. The vetch crop parameters, which were calibrated by the Agricultural Policy/Environment eXtender (APEX) model, were used for the SWAT biomass estimation. The SWAT model setup also included rainfed crops whose parameter was also determined by the APEX model during the ex-ante and ex-post studies. Since the aim of the study was to estimate the potential of scaling livestock feed production in the rainfed agriculture system, vetch biomass production was estimated only in the existing rainfed agricultural land. Although all the biophysical processes for SWAT were estimated at the Hydrological Response Units (HRUs) level, the estimates were aggregated by area-weighting at the sub-basin level, which was a 10 km grid.

The calibrated and validated SWAT model was used to estimate the blue water and green water resources at a 10 km grid. Bluewater refers to the liquid water in rivers and aquifers, while the green water is naturally infiltrated rain, which is attached to the soil particles and accessible to roots (Falkenmark and Rockstrom, 2004; Rockstrom et al., 2010). In terms of SWAT estimates, blue water is the sum of the water yield and deep groundwater recharge (cf. J Schuol et al., 2008). Water yield is the total amount of water leaving the area and entering the main channels, while deep groundwater recharge is the amount of water from the root zone that recharges the deep aquifer. There are two forms of green water: green water flow and green water storage. The green water flow is the invisible water that evaporates from the soil and plant canopy and that transpires through plants stomata (Rockstrom and Falkenmark, 2004). While the green water storage is the amount of water that is stored in the soil moisture.

Potentially suitable land for irrigated fodder

The reclassified and weighted factors were overlaid to identify preliminary fodder suitability maps. The constraints limiting the use of the land for fodder production were then excluded to further refine the maps and identify the potential suitable land for fodder production. The preliminary suitability map provided values that range between 48% to 94% for Napier, 42% to 91% for alfalfa, 46% to 94% for desho, 39% to 93% for vetch, and 38% to 94% for oats. The lower value range represents the lowest suitable land area for the respective fodder crop, and the upper value represents the most suitable land for the respective fodder production (Figure 2a to e). The most suitable land was extracted with a variable threshold above 80% with a 1% incremental; the area above the threshold is shown in Figure 2f. For example, at a threshold of 85%, there were thousands of suitable areas ranging from 1 km2 to 35 km2. At the 85% threshold, nearly 2% of the landmass was suitable for Napier production using surface irrigation, and at the 80% threshold, nearly 9% (22,600 km2) of the land was suitable for surface irrigation. The suitability analysis indicated that the country has the largest suitable area for Desho production (31%) followed by Vetch (23%), Napier (20%), Alfalfa (13%), and oats (12%) (Figure 2f).

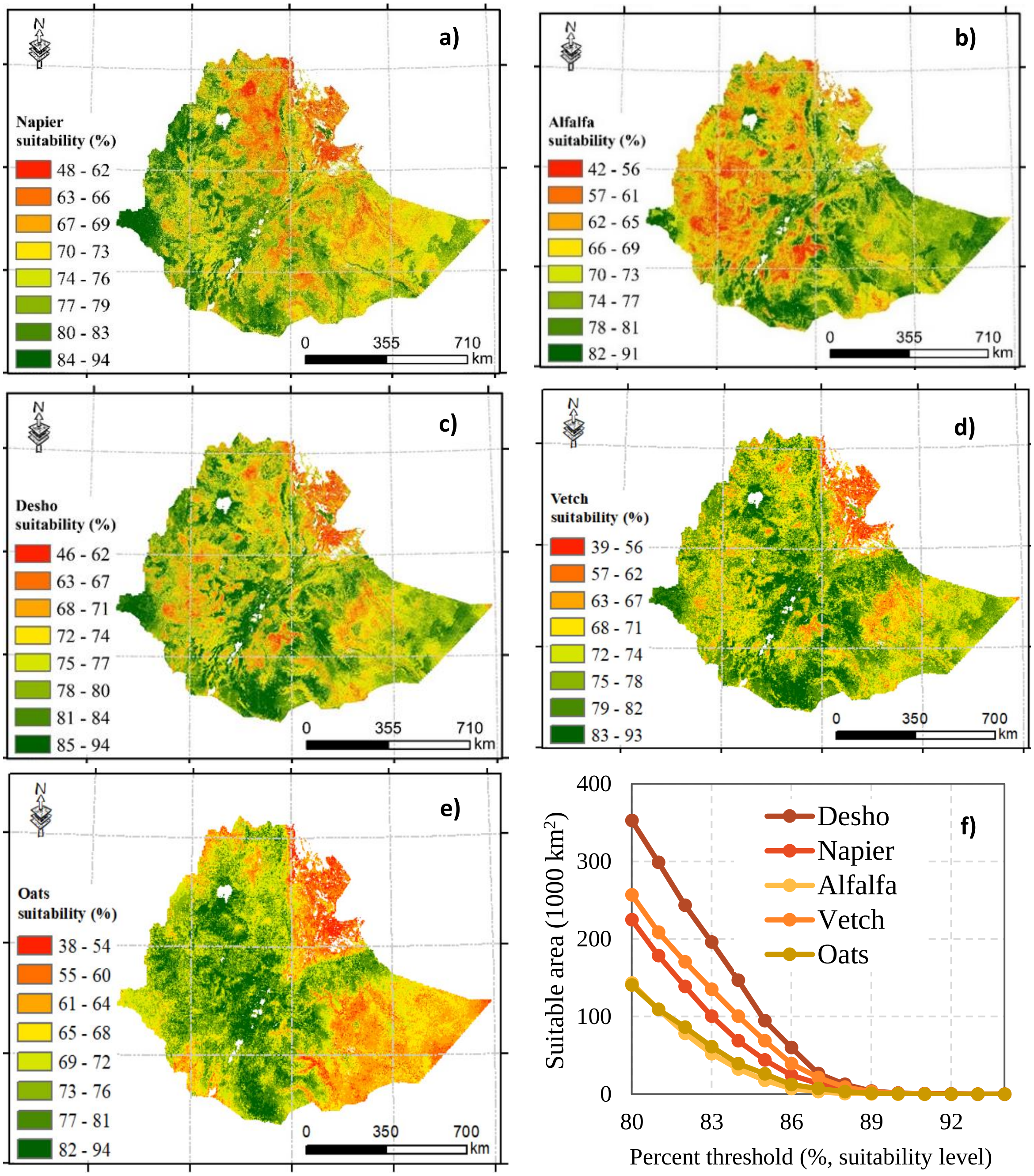

Figure 2. Suitability for irrigated fodder production: (a) Napier suitability, (b), Alfalfa suitability (c) Desho suitability, (d) Vetch suitability, (e) Oats suitability, and (f) potential suitable irrigated fodder production (in 1000 km2) at different threshold levels. The values in the map represent the level of suitability; the higher the value represents the most suitable the area and vice versa.

The potential fodder production areas (suitability threshold > 80%) were extracted for the major river basins in Ethiopia. This type of analysis can help the development of a livestock mater plan which ultimately helps to prioritize land use planning at the basin level. Which is critical to achieving food and nutrition security at household, regional and national levels. The result indicated that the largest basin in Ethiopia, the Blue Nile Basin (locally called Abbay) has the largest area suitable for fodder production followed by Genale-Dawa and Wabi-Shebelle, respectively. Abbay River Basin has the highest suitable area for Napier and oats, while Genale-Dawa has the largest suitable area for desho, alfalfa, and vetch.

Groundwater availability in suitable fodder producing areas

The average groundwater potential yield in the highly suitable land (threshold >85%) is ~4l/s; 5.8l/s; ~4.3l/s, ~4.5l/s, and ~3.7l/s for Napier, alfalfa, desho, vetch and oats respectively. The depth to groundwater estimated using the BGS data indicated that on average groundwater could be accessed at an average depth of 17m, 22m, 27 m, 14m, and 20m for Napier, alfalfa, Desho, vetch and oats, respectively. The groundwater assessment indicated substantial potential and accessibility for small-scale fodder production using simple water lifting technology. Since there is a higher rainfall variability in Ethiopia, groundwater can serve as a source of irrigation buffering the rainfall variability and short-term drought.

Biomass production in candidate fodder producing lands

Any rainfed agricultural land was considered as a candidate land for fodder production. The potential to produce vetch using irrigation during the dry season was estimated in these candidate lands across Ethiopia. The analysis was calculated over the long-term (1980-2010) and intended to estimate potential production during optimal and sub-optimal climatic conditions. The optimal climatic conditions refer to periods where there was maximum vetch biomass yield, while the sub-optimal conditions refer vice versa. Both shallow groundwater aquifer and surface water were considered as a source of irrigation since the water resources amount and source are different at different locations.

The vetch dry matter biomass yield may range between ~8.20 ton/ha and ~18.00 ton/ha during the optimal climatic conditions (Figure 3a). The highest vetch biomass was estimated in the central and low land parts of Ethiopia, where the temperature is low. The vetch biomass yield may range between <2 ton/ha and ~13 ton/ha during the sub-optimal climatic years (Figure 3b). The lowest vetch biomass was observed in Abay, Awash and Wabi Shebele basins. Tin areas where the climatic variability is less, like the Lake Tana basin, the vetch biomass yield was not changing significantly across the landscape.

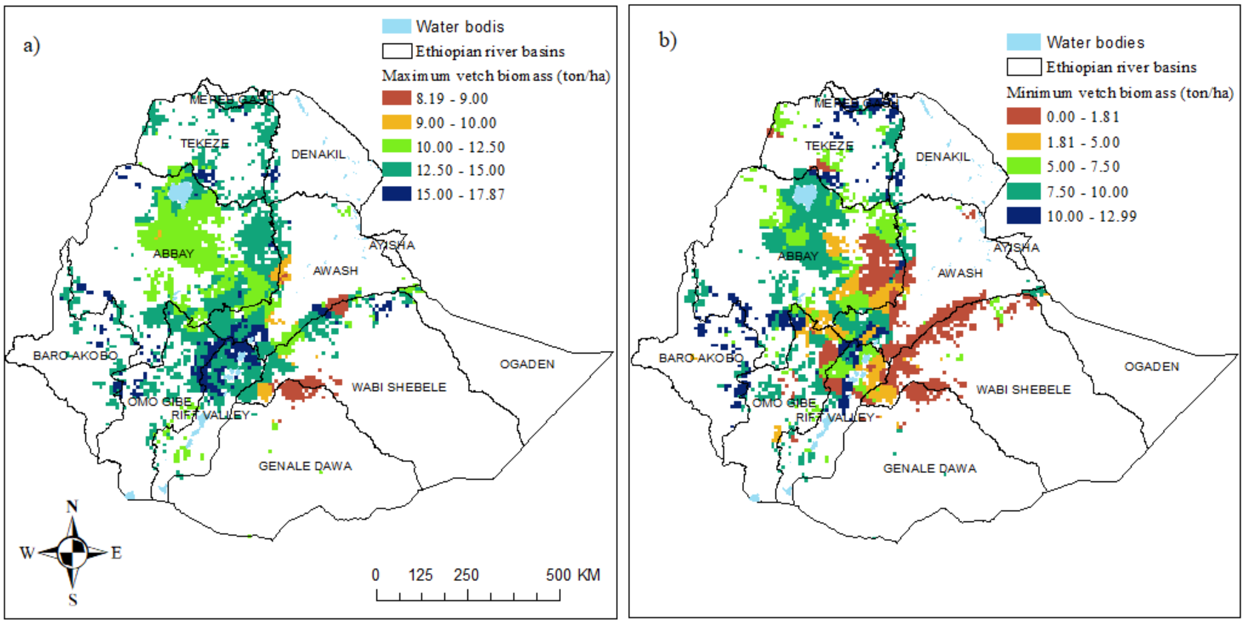

Figure 3. Vetch biomass production on rainfed agricultural lands using irrigation during the dry period; vetch biomass (ton/ha) during a) optimal, and b) sub-optimal climatic conditions. The white areas represent other land use types than rainfed agricultural land such as grassland, bushland, forest, etc. These areas were not considered for irrigated agriculture since they are already providing other ecosystem services.

Blue and green water resources in candidate fodder producing land

The blue water generated in the rainfed agricultural lands ranges between ~3 mm and 1525 mm (Figure 4a). Accounting the green water storage into the water resources matrix increased the available blue and green water storage in the rainfed agricultural lands. For example, a blue water focus analysis indicated that in about 40% of the rainfed agricultural land, the blue water resource amount was more than 500 mm. However, when the green water storage was added in the blue water, about 51% of the agricultural land had a blue water and green water storage amount of more than 500 mm (Figure 4b). More than 30% of the rainfed agricultural land has a blue and green water storage of more than 750 mm. This shows that there is a substantial amount of agricultural land and potential irrigation water to cultivate vetch biomass feed for livestock in Ethiopia.

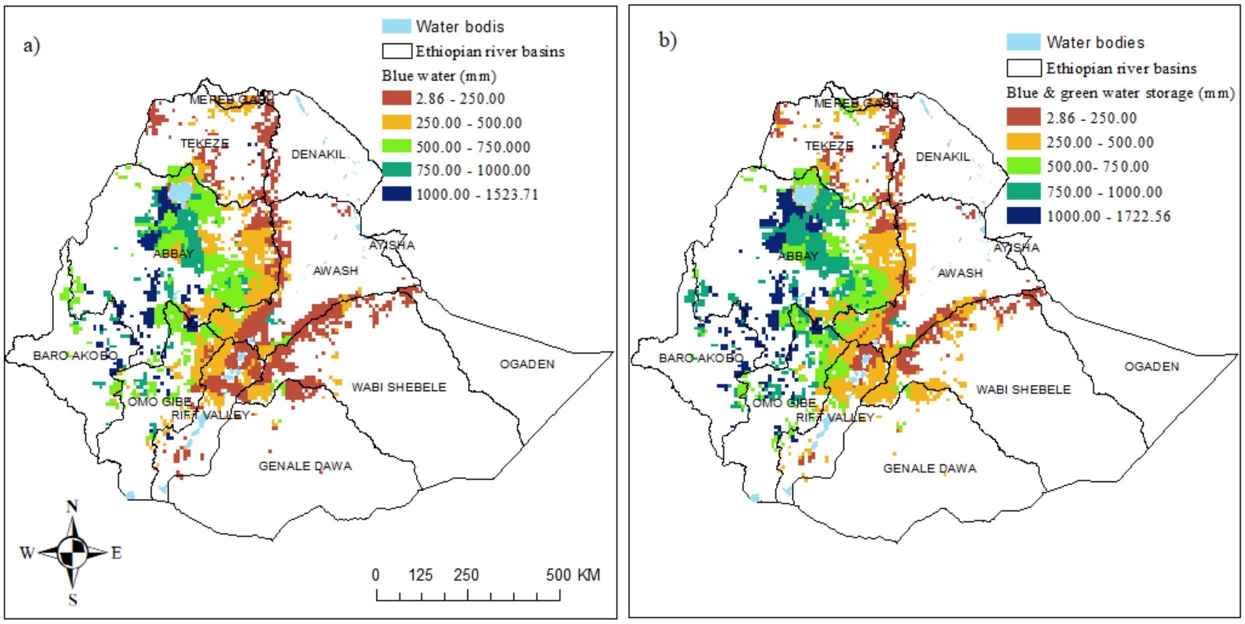

Figure 4. Long-term average annual available water resources over agricultural fields in Ethiopia; a) blue water (mm), and b) blue water plus green water storage (mm). The white areas represent other land use types than rainfed agricultural land such as grassland, bushland, forest, etc. These areas were not considered for irrigated agriculture since they are already providing other ecosystem services.

Concluding remarks

This study focuses on providing a spatially explicit land suitability analysis for fodder production in Ethiopia. Though the country possesses a significant livestock population, the largest in Africa, productivity in the sector is constrained by inadequate quantity and quality of feed supply throughout the year to satisfy the demand of livestock. If managed successfully, the livestock production system has the ability to improve the nutritional status and income of the people. The suitability analysis indicated that there is a significant land area suitable for increased fodder production in Ethiopia. The identified suitable land is also situated in an area where there is substantial potential for accessible groundwater for small-scale fodder production using simple water-lifting technologies. The disaggregated fodder production site also indicated that the largest river basin Abbay (Blue Nile) has the largest area suitable for fodder production followed by Genale-Dawa and Wabi-Shebelle, respectively.

This study provides valuable insights for decision-makers, practitioners, and the private sector interested in scaling fodder production in Ethiopia. This study can be used to advise policy and decision-makers in prioritizing fodder production intensification nationally. We recommend the government promote fodder production in appropriate areas as a potential cash crop.

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

Sub-Activity 2.2.4. Examining how credit and yield-based index insurance can increase resilience

Background

In the face of severe climatic shocks, households in developing countries often reduce assets to smooth consumption, 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 tend to refrain from investing and engaging in profitable but risky economic activities, choosing rather to invest in traditional technologies that have a low rate of return.

Crop insurance can be used to mitigate risks and assure families maintain assets and consumption levels (WB, 2011). Yield risk management schemes have been tried in developing countries 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 as well as the 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 countries 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 crops losses in the event of a shock (Miranda & Malunga, 2016). The increase in use of meteorological stations (although costly) and satellite imagery can help understand the relationship between weather and crop production for a better design of 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, the use of crop growth models based on crop water requirements which have high potential to predict aggregate yields and its complex relationship with weather is recommended (Miranda & Malunga, 2016).

ILSSI is developing an integrated approach combining the Agricultural Policy/Environmental eXtender model and farm simulation (FARMSIM) models to generate an accurate yield index but 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 especially the consideration of several plant growth factors will: 1) reduce the level of the basis risk, improve the yield prediction and index; 2) provide a better assessment of potential indemnities schedules and household resilience level under different insurance schemes.

Climate risk area mapping

The study followed distinct steps to identify climate risk areas for rainfed agriculture and simulate historical crop yield. First, the climate risk areas for rainfed cropping systems across Ethiopia were identified using 509 rainfall stations operated by Ethiopian National Metrological Agency (ENMA). The monthly rainfall data were used to identify the different rainfall regions in Ethiopia and the rainfall data were aggregated across the different rainfall regimes for the rainfed growing period. The growing season rainfall was interpolated with Inverse Distance Weighting (IDW) and the rainfall was classified into multiple rainfall regimes to identify high-risk zones for rainfed production. The risk areas were identified by evaluating the monthly rainfall distribution in addition to the amount of rainfall throughout the growing period. After identifying the rainfall risk area, historical crop yield was simulated using the APEX model for the selected site vulnerable to the risk of crop failure due to rainfall variability. The simulated crop yield was calibrated to capture the observed crop yield data collected from the Ethiopian Central Statistical Authority (CSA). The CSA yield data were reported at the zonal level for the period 2003 to 2015. The calibrated and validated APEX model with observed crop yield data for the period 2003 – 2015 was used to predict crop yield data for the period 1980 to 2015 using the local climate data and agricultural management practices.

Areas susceptible to rainfall variability and risk

The rainfed growing season rainfall across the different rainfall regimes is shown in Figure 5. The average rainfed growing season rainfall across the three rainfall regimes is ~980 mm, 445, and 390 mm in Regime I, II, and III, respectively. Higher rainfall variability is observed in Regime II with a 34% coefficient of variation, while Regime I has the least rainfall variability with a 20% coefficient of variation.

The majority of Regime I, ~90% of the area receives more than 750 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 might not be feasible. Instead, supplemental irrigation and development of infrastructures such as rainwater harvesting, water storage structures, 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. Some localities, where the growing season rainfall is less than 300 mm and which has extremely higher rainfall variability, should be dedicated to drought resistance forage/fodder crops to support the livestock system. In those areas, crop insurance options will not be viable since there may be more payouts than collected premiums or a hike in premium to cover payouts which are not sustainable for farmers and insurance companies.

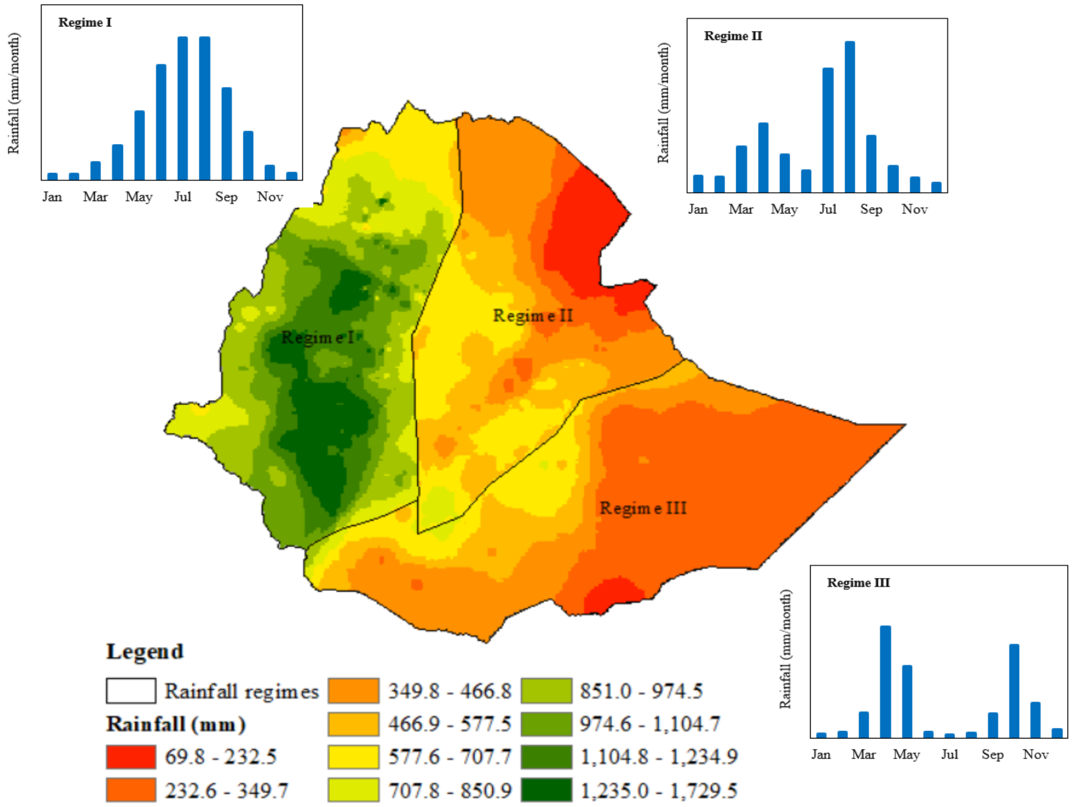

Figure 5. The boundary of rainfall regimes in Ethiopia with an average monthly rainfall pattern and maize growing season average rainfall interpolated with Inverse Distance Weighting (IDW, 1990 - 2010).

Insurance development site selection and yield simulation

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. Following this criteria, Lemo Southern Nations Nationalities Region was selected for this study. Maize growing season rainfall data analyzed for Lemo area indicated an average rainfall of 600 mm with a standard deviation of 85 mm (1990 – 2018). The positive values indicate an above-normal growing season rainfall while negative values represent below normal rainfall. The analysis indicates that ~10% of the time the growing season rainfall was below 500mm.

The simulated corn yield of the APEX model for Lemo site using the historical data is shown in Figure 6. The model calibration is in progress and will be fin-tuned further as more observed crop yield data will be collected. The preliminary simulated yield indicated a strong correlation with the simulated yield ($R^2 = 0.98$). The simulated corn yield varies between 1.45 and 2.15 t/ha with an average yield of 1.8 t/ha (1990–2018). The histogram of simulated yield is shown in Figure 6, which indicated 10.4% of the time the yield was <1.65t/ha.

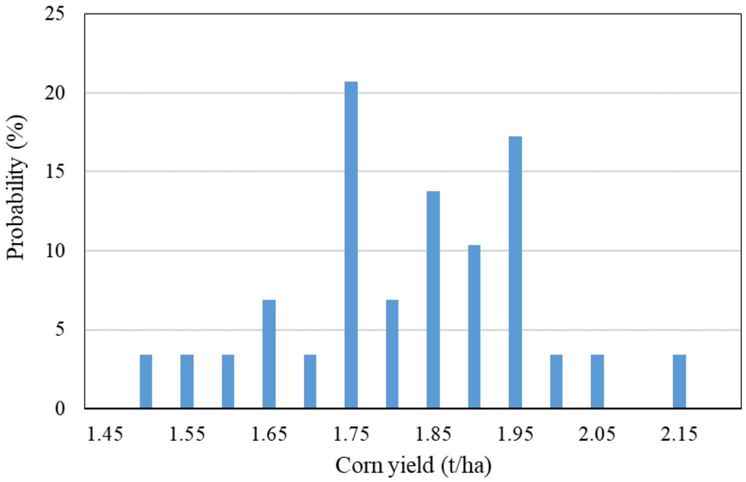

Figure 6: Preliminary simulated yield of corn with the APEX model in Lemo area (1990 – 2018)

Yield-based crop insurance methodological approach and scenario analysis

The yield-index insurance study integrated several methods to develop mitigation and resilience tools for smallholder farmers in order to reduce risks associated with climate change. First, the study identified climate risk areas for rainfed production system to build climate resilient yield-based index insurance in Ethiopia. Second, the APEX model, a biophysical model developed to evaluate the effect of agricultural management practice on plant growth, yield and environmental sustainability, will be used to simulate crop yield distribution. The historical yields generated by APEX are used as input to determine the yield index and the subsequent premiums and indemnities of the crop insurance. Third, a farm-level Monte Carlo simulation model (FARMSIM) is used to simulate the economic and nutritional benefits of alternative technologies and scenarios including yield index insurance schemes scenarios. A crop index insurance component of the model evaluates the benefits of different crop insurance coverage levels on the farm's economic viability. In this study the Monte Carlo simulation approach is applied to calculate stochastic payouts (probability of indemnities) as well as other economic and nutritional benefits for the baseline and alternative scenarios under the different insurance coverage levels.

The proposed integrated modelling approach to study crop insurance system would use the following formula to calculate premiums and indemnities for a given village or region. Specifically, since the fair premium is the expected indemnity that will be paid for each policy, individual realized indemnities are calculated as follows:

*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 calculated 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 a 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).

Scenario analysis and Index insurance schemes

FARMSIM data is entered in parallel for the baseline and alternative scenarios. In this study, we consider ten scenarios based on the crop insurance coverage level and use of agricultural input (fertilizer) with minimal irrigation. They comprise a baseline scenario with current agricultural practices (minimal fertilizer and irrigation use) and no insurance coverage and nine alternative scenarios implementing different insurance coverage levels and use fertilizer to grow crops. Farmers in alternative scenarios can elect to insure their crops at a fraction of average 32 years historical maize yield generated by the APEX model with the fractions set at 0.5, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80 and 0.85 coverage. The premiums increase for higher insured fractions. A coverage level (e.g. 0.70 or 70 percent), is simply the percentage of loss against which the producer desires to be covered. Coverage level can be used by the government to determine subsidy level in case government decides to intervene and help farmers with insurance purchase. Generally, the subsidy decreases at higher insurance coverage levels.

Baseline: Current farming systems + minimal fertilizer and irrigation + no insurance
Alt.1—Insur0: Improved farming systems with Fertilizer use + no insurance
Alt.2—Insur0.50: Improved farming systems with Fertilizer use + Insurance at 0.50 coverage
Alt.3—Insur0.55: Improved farming systems with Fertilizer use + Insurance at 0.55 coverage
Alt.4—Insur0.60: Improved farming systems with Fertilizer use + Insurance at 0.60 coverage
Alt.5—Insur0.65: Improved farming systems with Fertilizer use + Insurance at 0.65 coverage
Alt.6—Insur0.70: Improved farming systems with Fertilizer use + Insurance at 0.70 coverage
Alt.7—Insur0.75: Improved farming systems with Fertilizer use + Insurance at 0.75 coverage
Alt.8—Insur0.80: Improved farming systems with Fertilizer use + Insurance at 0.80 coverage
Alt.9—Insur0.85: Improved farming systems with Fertilizer use + Insurance at 0.85 coverage

Several assumptions that include the insurance coverage levels (0.50 – 0.85) were made to carry out this study. Also, an insurance policy approach where the purchase of a crop insurance is associated with the acquisition of agricultural input was followed. In this approach there is an agreement stipulating that in the case of a crop failure, the insurance payment (indemnities) is used toward paying the loan on agricultural input.

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

Future Climate Change data – Ethiopia and Ghana

General Circulation Models (GCMs) have been used to predict climate change for the coming century. The climate outputs were obtained from the fifth phase of the Coupled Model Inter-comparison Project (CMIP5, (Taylor et al., 2012)). Since the horizontal resolution of most GCMs making the CMIP5 centennial projections are in the order of 1-2°, they may not represent important local forcing features, such as complex topography, land surface heterogeneity, coastlines, and regional water bodies. Hence GCM outputs may not represent extreme weather events, which are of vital significance to study impacts of climate change on social-ecological resilience (Jones et al., 2011). Hence, RCMs were used to address the scale gap between climate data requirements at the regional level and what is available in CMIP5 outputs.

The selection of the GCMs and RCMs was based on existing research in sub-Saharan Africa in representing the historical climatology. 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 outputs from these GCMs were regionalized using the Consortium for Small-scale Modeling (COSMO) Climate Limited-Area Model (CCLM) and Max Planck Institute Regional Model (REMO) RCMs (Table 2). These RCMs were selected based on their reasonable performance in Africa (Kim et al., 2014; Nikulin et al., 2012; Worku et al., 2018). The RCM outputs were acquired from the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative (Jones et al., 2011) from the Earth System Grid Federation (ESGF, 2020) website.

Table 2. Names of studied General Circulation Models (GCMs) and Regional Climate Models (RCMs)

GCM	Institute
CNRM-CM5	Centre National de Recherches Météorologiques
EC-EARTH	Consortium of European Research Institutions and researchers
MPI-ESM-LR	The Max Planck Institute for Meteorology Earth System Model
RCM	**Institute**
CCLM	COnsortium for Small-scale MOdeling (COSMO) Climate Limited-Area Model (CCLM)
REMO	Max Planck Institute Regional Model

Since relying on a single climate model output may not capture the uncertainty in climate change analysis, several studies (Dosio et al., 2015; Endris et al., 2013; Nikulin et al., 2012) recommended the use of an ensemble approach (i.e., use of bias-corrected data provided by several climate models and downscaling methods). Hence, this study considered multiple GCM derived RCM model outputs for climate change analysis. Besides the use of the ensemble approach, future climate data simulations forced by two Representative Concentration Pathways (RCPs) were used to capture the uncertainty in the climate change emission uncertainties. The two RCPs that have been considered were related to a midrange mitigation emissions scenario (RCP4.5) and a high emissions scenario (RCP8.5) (Taylor et al., 2012). The labels for the RCPs (i.e., 8.5, 4.5, etc.) provide an approximate estimate of the radiative forcing in the year 2100 relative to preindustrial conditions (Taylor et al., 2012). For example, the radiative forcing in RCP8.5, which is also called the "high" scenario, increases throughout the twenty-first century before reaching a level of about 8.5 W/m2 at the end of the century.

Bias correction of climate change data

Temperature and rainfall data from RCMs may have biases due to systematic model errors, which may occur due to system conceptualization, discretization and spatial averaging within grid cells (Rathjens et al., 2016; Teutschbein and Seibert, 2012). Such biases make direct use of simulated RCM climate data as input to hydrological models problematic since it may convey misleading estimates. Therefore, biases from RCM climate outputs should be corrected to minimize the discrepancy between observed and simulated climate variables on a daily time step, and thereby to reasonably predict biophysical variables with models using the corrected climate data.

There are several approaches to correct such biases, such as linear scaling, local intensity scaling, power transformations, variable scaling, and distribution mapping (Teutschbein and Seibert, 2012). Although most of these methods provided satisfactory performance, the distribution mapping was found the best method to correct biases in rainfall and temperature climate outputs (Worku et al., 2020; Teutschbein and Seibert 2012). Therefore, the distribution mapping method was used to correct the biases of RCMs that are used to assess the impact of climate change on social-ecological resilience in Ethiopia and Ghana. The bias correction was conducted using the Climate Model data for hydrologic modeling (CMhyd, Rathjens et al., 2016) tool. CMhyd helps to extract, and bias-correct data from global and RCMs based on gauge observed rainfall and temperature data. The bias correction for Ethiopia was conducted based on 203 observed rainfall and 123 observed maximum/minimum temperature stations, while the bias correction for Ghana was based on 68 observed rainfall and maximum/minimum temperature stations. The observed climate data that was used for the bias correction in both countries covers the period 1990 to 2013. The bias-corrected climate change data was generated for the period until 2100.

Estimating climate extremes to assess resilience

The climate change data was examined in terms of impacts on extreme climate and weather events, which have detrimental significance to society and ecosystems (IPCC, 2012). As such, studying the climate and weather extreme events is helpful to assess impacts of climate change on social-ecological resilience. 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). Due to their robustness and straightforward calculation and interpretation, the indices have been used in multiple applications such as detection and attribution studies, regional impact analysis, and evaluating downscaling methods (Bürger et al., 2012; Min et al., 2011; Morak et al., 2011; Sillmann et al., 2013; Worku et al., 2019). The indices were estimated based on daily rainfall and maximum/minimum temperature data. The studied indices are presented in Table 3 with their description. This annual report presents extreme weather and climate indices for selected climate stations in Ethiopia, where the best available observed climate data is available for bias correction and comparison. The studied stations are evenly distributed across Ethiopia and represent well different regions of the country. The analysis for Ghana will be reported in the coming semi-annual and annual reports. Although the bias correction was conducted for the period until 2100, the extreme weather and climate extreme analysis was done for the period until 2050 for the near-term projection of the coming 30 years (WMO, 2017).

Table 3. 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

Rainfall indices to assess impacts of climate change

Annual total wet-day precipitation

The annual total wet-day rainfall for the coming 30 years showed mostly a decrease in most of the studied stations and models (Figure 1). The ensemble mean of the studied RCMs also showed a decrease in the median annual rainfall compared to the observed annual rainfall (1983-2013) in most of the stations. All the CCLM4 RCMs showed a clear decrease in total annual rainfall in all of the stations. However, the REMO RCMs (i.e. EC-EARTH and MPI-ESM-LR) showed an increase in the median annual total wet-day rainfall in some of the stations (e.g. Addis Ababa, Awassa, and Nekemet) in both RCPs (i.e. 4.5 and 8.5). In relative terms, the two RCPs did not show a consistent increase or decrease in annual total rainfall. For example, the CCLM4(EC-EARTH) model provided higher rainfall for the RCP 4.5 (than RCP 8.5) in Addis Ababa, Bahir Dar, Combolcha, Debre Zeit, Jimma, Mekelle, and Nekemet stations; while for the same model, RCP 8.5 provided higher rainfall in Arba Minch, Awassa, Dire Dawa, and Negele stations. The ensemble mean also showed that the 4.5 RCP provided higher median annual rainfall in most of the stations (e.g. Addis Ababa, Awassa, Combolcha, Debre Zeit, Mekelle, and Negele). For the historical climate, except Addis Ababa and Mekelle, all the other stations showed an increasing trend of annual total rainfall (Figure 2X). The trend for the coming 30 years (2021-2050) by the models showed an increasing trend in some stations (and models) and a decreasing trend in other stations (and models) (Figure 7).

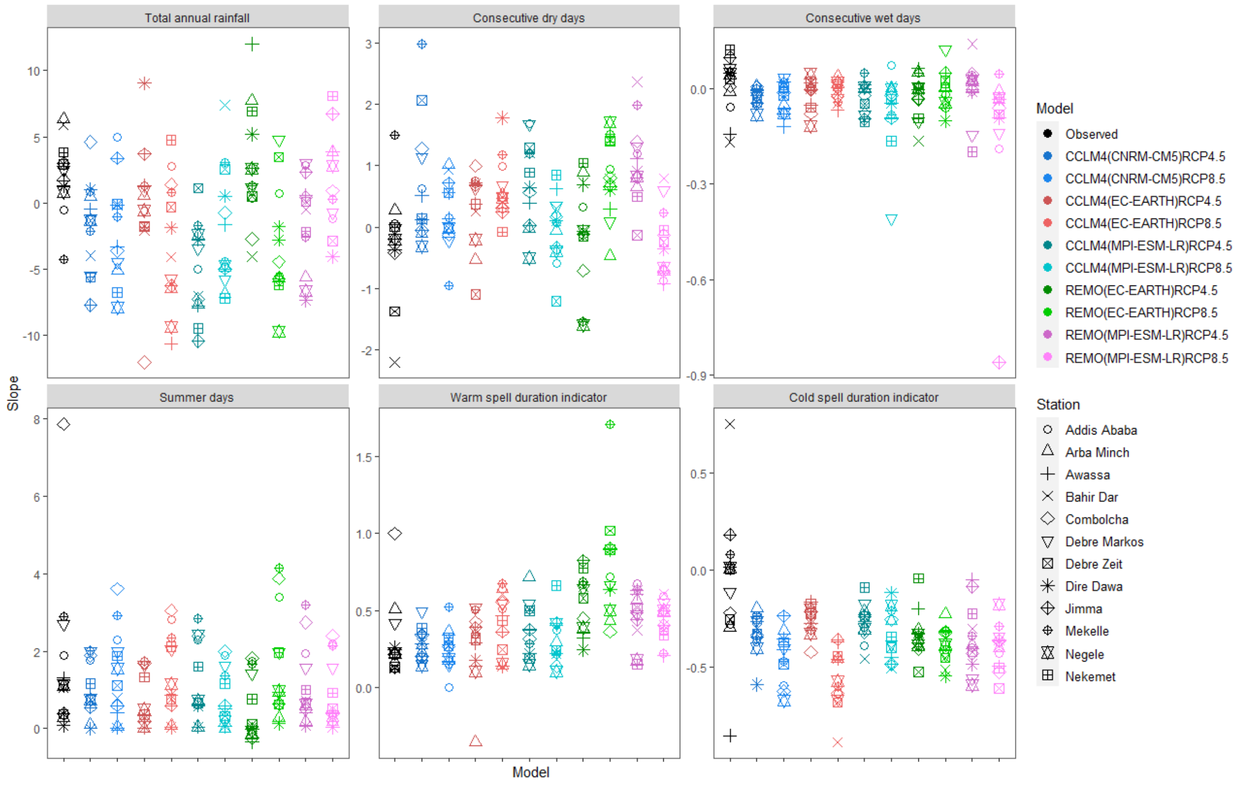

Figure 7. Trends of indices for historical climate (1984-2013) and projected climate for 2021-2050 using models in 11 studied stations in Ethiopia. A slope >0 shows an increasing trend, and vice versa. Refer Table 2 for the names of the studied General Circulation Models (GCMs) and Regional Climate Models (RCMs) for the 4.5 and 8.5 Representative Concentration Pathways (RCPs).

Number of days above 1 mm

In most of the studied stations, all the models projected smaller number of wet-days (rainfall >= 1 mm) for the coming 30 years (2021-2050) compared to the past 30 years of 1984-2013 (Figure 8). However, the CCLM models generally projected smaller number of rainfall days compared to the REMO models. In terms of the RCPs, consistent pattern in the number of wet-days was not observed. For example, the CCLM(EC-EARTH) 8.5 RCP showed higher number of wet-days in Arba Minch, Awassa, Dire Dawa, Jimma, Negele and Nekemet as compared to CCLM(EC-EARTH) 4.5 RCP. On the other hand, the CCLM(EC-EARTH) 4.5 RCP showed more number of wet-days in Addis Ababa Bahir Dar, Combolcha, Debre Markos, Debre Zeit, Mekelle.

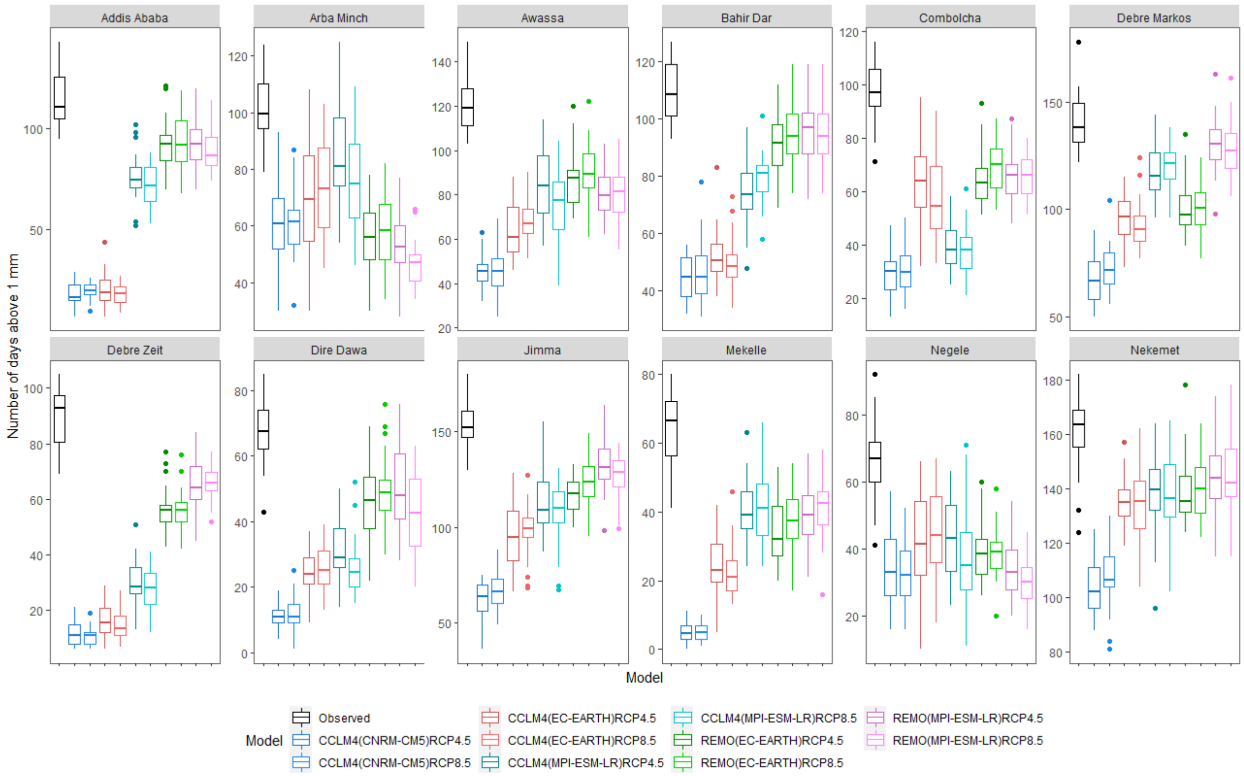

Figure 8. Boxplot showing annual number of days when rainfall >1 mm. The future time period for the climate models ranges between 2021 and 2050 and the historical climate ranges between 1984 to 2013. Refer Table 2 for the names of the studied General Circulation Models (GCMs) and Regional Climate Models (RCMs) for the 4.5 and 8.5 Representative Concentration Pathways (RCPs).

Very heavy precipitation days (rainfall >= 20 mm)

Compared to the number of days of rainfall >= 1 mm, the number of projected heavy rainfall days (i.e. rainfall >= 20 mm) by most of the models was closer to the historical number of heavy rainfall days in all of the stations. However, the CCLM RCM models provided smaller number of very heavy rainfall days compared to the historical rainfall in both 4.5 and 8.5 RCPs for most of the studied stations. While the REMO RCM models provided higher number of very heavy rainfall days in some station (e.g. Addis Ababa, Awassa, Bahir Dar, Combolcha, Debre Markos, Debre Ziet, Nekemet). Of the studied stations the smallest number of very heavy rainfall days were projected by the CCLM4(CNRM_CM5) RCM for the 4.5 RCP in Mekelle, which was 3.5 mm. While the highest number of very heavy rainfall days were projected by the REMO(MPI-M_MPI-ESM-LR) RCM and 8.5 RCP in Nekemet. The median number of very heavy rainfall days for the period 2021-2050 in Mekelle was 3.5. The median number of very heavy rainfall days for the period 2021-2050 in Nekemet was 39.5.

Consecutive dry days

Higher maximum number of consecutive dry days (per year) were found in the projected climate data of most of the models (2021-2050) compared to the historical observed climate (1984-2013) in all of the studied stations (Figure 9). For example, for the Mekelle station where the highest number of consecutive dry days was observed, the median number of consecutive dry days (per year) for the historical observed climate (1984-2013) was 104; however, the median number of consecutive dry days (per year) for future climate of 2021 to 2050 ranged between 133.5 (for REMO(MPI-ESM-LR) in the RCP85) and 260 (for CCLM4(CNRM-CM5) in the 4.5 RCP). Generally, CCLM4 RCMs projected higher number of consecutive dry days in all of the studied stations.

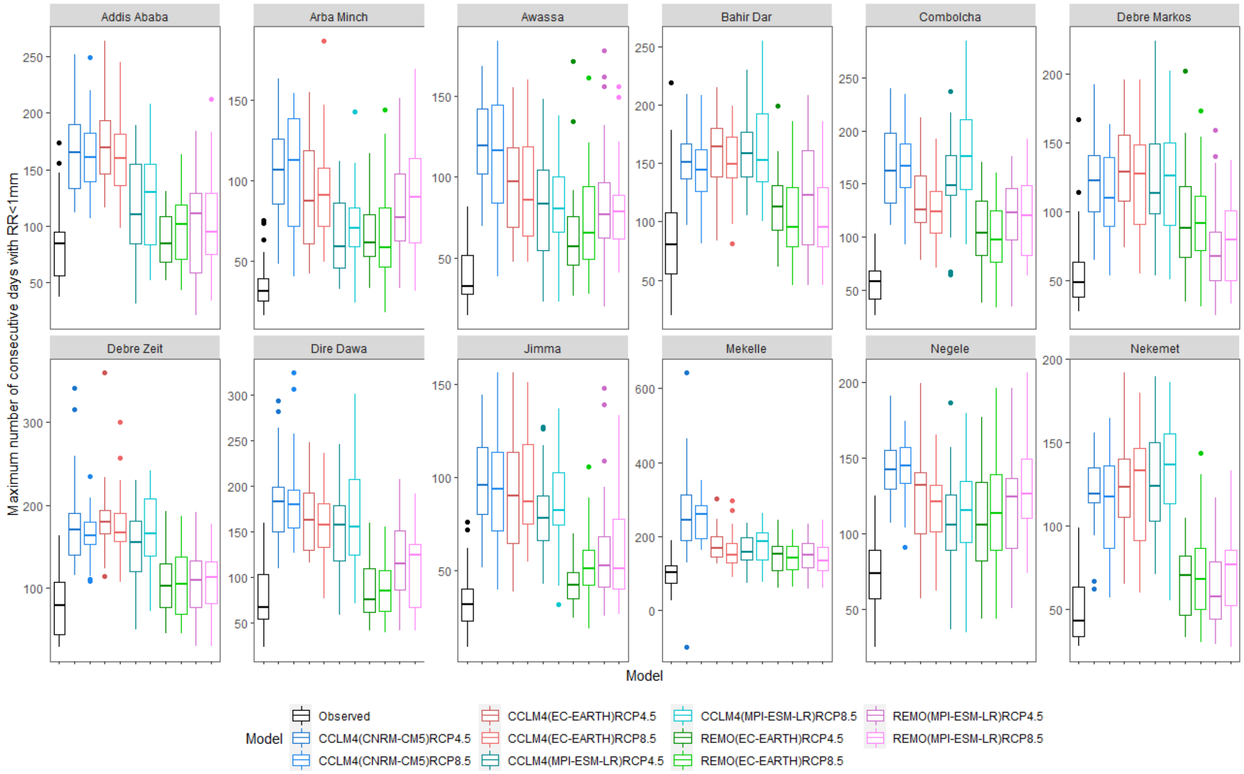

Figure 9. Boxplot showing maximum number of consecutive days (per year) with rainfall < 1 mm for the future period of 2021 to 2050, and historical period of 1984 to 2013. Refer Table 2 for the names of the studied General Circulation Models (GCMs) and Regional Climate Models (RCMs) for the 4.5 and 8.5 Representative Concentration Pathways (RCPs).

Consecutive wet days

The projected maximum number of consecutive wet days (i.e. days with rainfall >1 mm) per year were smaller than the historical observed climate in the majority of the studied stations. For example, all the climate models showed a decrease in the median projected maximum number of wet days for the period 2021-2050 compared to the historical observed climate period of 1983-2013 in the Addis Ababa, Combolcha, Debre Zeit, Dire Dawa, and Mekelle stations. Among the studied stations, the smallest number of consecutive wet days were observed in Debre Zeit and Mekelle stations (median of 2 days) with the CCLM4(CNRM_CM5) RCM model for both 4.5 and 8.5 RCPs. The highest number of consecutive wet days were observed in Debre Markos station (median of 24 days) with the REMO(MPI_ESM_LR) RCM model and 4.5 RCP.

Temperature indices to assess impacts of climate change

Summer days

The projected number of summer days (i.e. annual count when the maximum temperature is >25 °C) for the period 2021 to 2050 in all the models and stations increased compared to the historical observed climate of 1984 to 2013. (Figure 10) In fact, the change is substantial in most of the stations except Arba Minch, and Dire Dawa, which have a higher historical observed temperature. However, even in these stations, some of the models projected higher number of summer days. Generally, the 8.5 RCP provided higher number of summer days than the 4.5 RCP in most of the models and stations. Trend analysis showed that the number of summer days has been increasing for the last 30 years (1984-2013), and it may continue the same in the coming 30 years (2021-2050) (Figure 8).

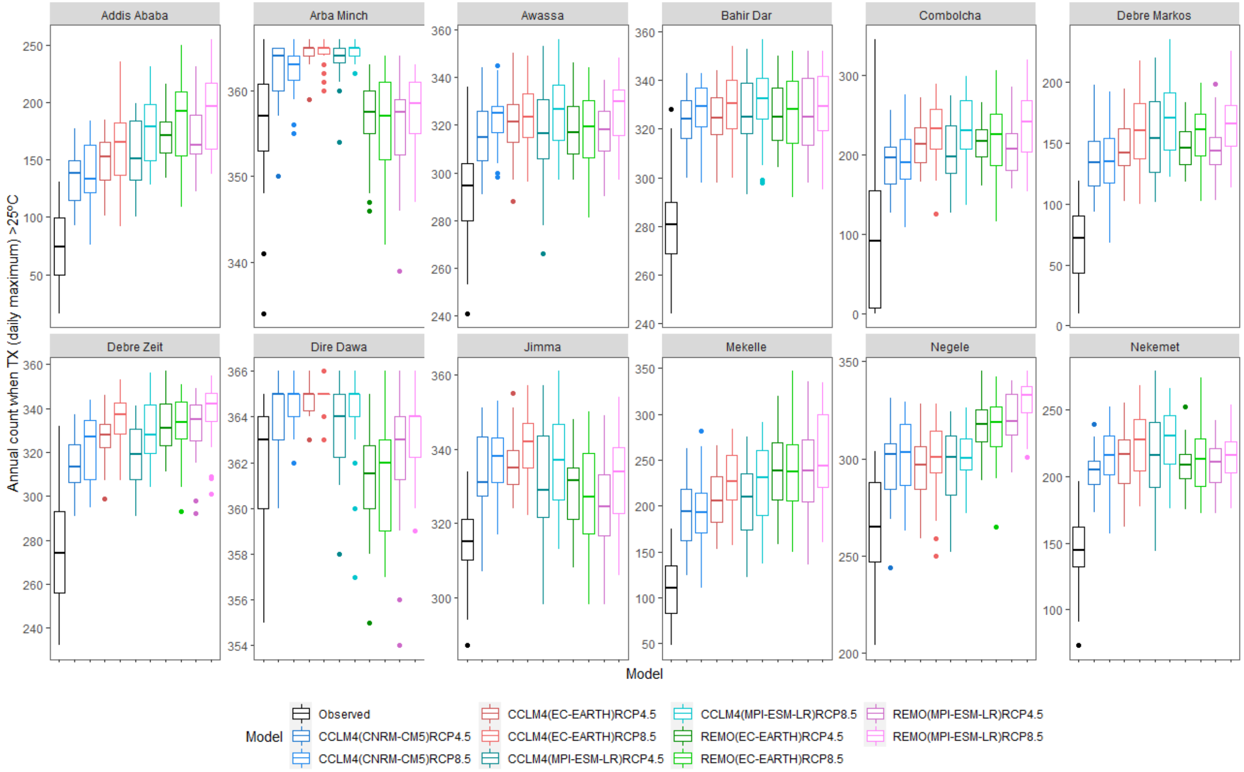

Figure 10. Boxplot showing the number of summer days (i.e. annual count of maximum temperature (TX) >25 °C for the future period of 2021 to 2050 and historical climate of 1984 to 2013. Refer Table 2 for the names of the studied General Circulation Models (GCMs) and Regional Climate Models (RCMs) for the 4.5 and 8.5 Representative Concentration Pathways (RCPs).

Warm spell duration indicator

The warm spell duration indicator (i.e., the annual count of days with at least 6 consecutive days when the maximum temperature is >90th percentile) for the historical observed climate (1984-2013) was zero in most of the stations (Figure 8). However, the projected warm spell duration with most of the models was more than zero in most of the stations. Only REMO downscaled MPI-ESM-LM GCMs (both 4.5 and 8.5 RCPs) provided zero values of warm spell duration indicator in some of the years (Figure 8). The trend analysis showed that most of the models showed an increasing trend of warm spell duration indicator except Arba Minch, Awassa, Dire Dawa, Jimma and Negele stations (Figure 2X).

Cold spell duration indicator

The cold spell duration indicator (i.e. annual count of days with at least 6 consecutive days when minimum temperature (TN) <10th percentile) projected by most of the models for the period 2021 to

2050 generally increased compared to the historical climate of 1984 to 2013 (Figure 9). The cold spell duration indicator showed a decreasing tend for the historical period (1984-2013) and future period of 2021-2050 except the current climate of Bahir Dar, Dire Dawa, Jimma, Mekelle, Negele and Nekemet (Figure 2X).

Concluding remarks
The historical and future climate indices showed that climate change will generally exacerbate the climate variability and climate risks in Ethiopia. Although there was not a consensus among the models on the total amount of annual rainfall trends, all the modeling results showed that the number of rainfall days (rainfall amount > 1mm) decrease compared to the historical rainfall amount. Likewise, the projected number of days with very heavy rainfall days (rainfall >= 20 mm) decreased in the majority of the studied stations, and RCMs. All the RCMs agree that the number of consecutive dry days may increase while the number of consecutive wet days may decrease in all of the studied stations in Ethiopia. Projections with the RCM models also indicated that the temperature may get warmer in the comping 30 years (2021-2050) compared to the historical climate (1984-2021). For example, the projected number of summer days by all the RCMs and in all of the studied stations were higher than the number of summer days during the historical climate. Likewise, the warm spell duration indicator was higher for the projected climate than the historical climate in all RCMs and studied climate stations. The climate change analysis, therefore, indicated that climatic risks will increase in Ethiopia in the coming decades.

The reduction in total annual rainfall, the increase in temperature which leads to an increase in actual evapotranspiration and increase in dry spells suggest that climate change will affect agricultural production in Ethiopia. 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 helps to enhance rainfed agriculture through provisioning of supplementary irrigation and additional production during the dry season. Cultivation of drought resistant crops and crop rotation has been suggested as among the best strategies to adapt to the risks of climate change. Land and water management practices (e.g. land rehabilitation, terracing, reforestation, etc) may also help to adapt the impacts of climate change as they enhance soil moisture in the watershed.

Assessing potential of small scale irrigation to improve cocoa production in West Africa region

Similar to fodder suitability analysis, the IDSS team has been developing a framework to identify suitable areas for cocoa production in the West Africa region. Once the suitable areas will be identified, biophysical models will be applied to assess the potential of small-scale irrigation to cultivate vegetables intercropped with cocoa seedlings. The intent of the cocoa research is to improve cocoa production in West Africa region, which is often experiencing water shortage especially in the early stage of the cocoa growth. This is a research in progress in which spatial data for the suitability analysis are in preparation, and cocoa land management data is being collected.

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

Simulated Economic and Nutrition Impacts of Irrigated fodder and crossbred cows on households in Lemo woreda of Ethiopia

The livestock sector is one of the main pillars of Ethiopia's economy for its contribution to agriculture and national gross domestic product (GDP). In smallholder mixed farming systems, livestock products provide nutritious food, additional emergency and cash income. Despite its importance, several constraints related to livestock production such as low livestock productivity, remain a major barrier to the development of the livestock sector in Ethiopia. Improving animal feed resources and breeds can have impacts on both household income and nutrition through the production, consumption and sale of animals and animal products. In this study in Lemo woreda, Upper Gana kebele of Ethiopia, small scale irrigation (SSI) technologies along with fertilizer were used to grow and improve yields of fodder (oats & vetch) with the purpose to feed native and crossbred cows and generate income. Supplementing feeding of crossbred cows with fodder is expected to increase milk production and animal weight which in turn will improve family nutrition and generate income.

A farm level economic and nutrition simulation model (FARMSIM) is used to evaluate the potential nutrition and economic impacts of the SSI technologies and crossbred cows on households in Lemo woreda, Upper Gana kebele of Ethiopia. The model simulates and forecasts for five years the current (baseline) crop and livestock farming system and an alternative system simultaneously. Annual net cash income (profit) and the benefit cost ratio are the economic key output variables while nutrition variables comprise average available daily intake of calories, protein, fat, calcium, iron, and vitamin A for an adult equivalent. In the baseline scenario, fodder is grown on limited land with minimal irrigation and fertilizer while in alternative scenarios, more land and fertilizers are allocated to fodder during the dry season due to irrigation.

Results showed that the annual average profit under alternative scenarios was between 2 and 4 times that of the Baseline scenario. However, the distribution results highlighted the risk associated with high production and water lifting tools (e.g. solar pump) costs from SSI technologies investment. The nutrition results showed that the quantities of crops and livestock products consumed by families in both the baseline and alternative scenarios met the minimum daily requirements for calories, proteins, iron, and vitamin A but were insufficient for calcium and fat. However, the increase in quantity of animal products consumption led to the increase in available proteins by 12%, fat by 24%, calcium by 73%, iron by 5% and vitamin A by 17% under the alternative scenarios associated with improved livestock production technologies and purchase option.

The above information has been summarized in a Research Brief by the Feed the Future Livestock Systems Innovation Lab, which co-funded the research.

Annex 1 References

Ahmed K., Tamir B., Mengistu A. (2016) Constraints, Opportunities and Challenges of Cattle Fattening Practices in Urban and Peri-Urban Kebeles of Dessie Town, Ethiopia. J Fisheries Livest Prod 4:2.

Asresie A., Zemedu L. (2015) Contribution of Livestock Sector in Ethiopian Economy: A Review. Advances in Life Science and Technology 29:79-90.

Bürger, G., Murdock, T.Q., Werner, A.T., Sobie, S.R., Cannon, A.J., 2012. Downscaling extremes-an intercomparison of multiple statistical methods for present climate. Journal of Climate 25, 4366–4388. https://doi.org/10.1175/JCLI-D-11-00408.1

Dile, Y.T, Essayas K Ayana, Abeyou W Worqlul, Hua Xie, R Srinivasan, Nicole Lefore, Liangzhi You, Neville Clarke, 2020. Evaluating satellite-based evapotranspiration estimates for hydrological applications in data-scarce regions: A case in Ethiopia. Science of the Total Environment 743 (2020) 140702. https://doi.org/10.1016/j.scitotenv.2020.140702

Dosio, A., Panitz, H.J., Schubert-Frisius, M., Lüthi, D., 2015. Dynamical downscaling of CMIP5 global circulation models over CORDEX-Africa with COSMO-CLM: evaluation over the present climate

Ecocrop. (2000) Ecocrop Database, FAO, in: F. a. A. O. o. t. U. Nations (Ed.), Rome.

ESGF, 2020. Earth System Grid Federation [WWW Document]. URL https://esgf-node.llnl.gov/search/esgf-llnl/ (accessed 1.4.20).

Falkenmark, M., Rockstrom, J., 2004. Balancing Water for Humans and Nature: The New Approach in Ecohydrology. Earthscan, London, UK.

FAO. (2011) Grassland Index. A searchable catalogue of grass and forage legumes.

Hiernaux P., Fernández-Rivera S., Schlecht E., Turner M., Williams T.O. (1997) Livestock-mediated nutrient transfers in Sahelian agro-ecosystems.

Hiernaux, P., Fernández-Rivera, S., Schlecht, E., Turner, M. and Williams, T.O. 1997. Livestock-mediated nutrient transfers in Sahelian agro-ecosystems.

Jones, C., Giorgi, F., G. Asrar, 2011. The Coordinated Regional Downscaling Experiment: CORDEX; An international downscaling link to CMIP5. CLIVAR Exchanges 16, 15–19.

Karl, T.R., Easterling, D.R., 1999. Climate extremes: Selected review and future research directions. Climatic Change. https://doi.org/10.1023/A:1005436904097

Kim, J., Waliser, D.E., Mattmann, C.A., Goodale, C.E., Hart, A.F., Zimdars, P.A., Crichton, D.J., Jones, C., Nikulin, G., Hewitson, B., Jack, C., Lennard, C., Favre, A., 2014. Evaluation of the CORDEX-Africa multi-RCM hindcast: Systematic model errors. Climate Dynamics 42, 1189–1202. https://doi.org/10.1007/s00382-013-1751-7

Klein Tank, A.M.G., Zwiers, F.W., Zhang, X., 2009. WMO Guidelines on Analysis of extremes in a changing climate in support of informed decisions. Climate Data and Monitoring 52.

Min, S.K., Zhang, X., Zwiers, F.W., Hegerl, G.C., 2011. Human contribution to more-intense precipitation extremes. Nature 470, 378–381. https://doi.org/10.1038/nature09763

Morak, S., Hegerl, G.C., Kenyon, J., 2011. Detectable regional changes in the number of warm nights. Geophysical Research Letters 38, 1–5. https://doi.org/10.1029/2011GL048531

Nikulin, G., Jones, C., Giorgi, F., Asrar, G., Büchner, M., Cerezo-Mota, R., Christensen, O.B., Déqué, M., Fernandez, J., Hänsler, A., van Meijgaard, E., Samuelsson, P., Sylla, M.B., Sushama, L., 2012. Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. Journal of Climate 25, 6057–6078. https://doi.org/10.1175/JCLI-D-11-00375.1

Rathjens, H., Bieger, K., Srinivasan, R., Arnold, J.G., 2016. CMhyd User Manual Documentation for preparing simulated climate change data for hydrologic impact studies.

Rockstrom, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., Qiang, Z., 2010. Managing water in rainfed agriculture - The need for a paradigm shift. Agricultural Water Management 97, 543–550.

Saaty T.L. (1977) A scaling method for priorities in hierarchical structures. Journal of mathematical psychology 15:234-281.

Saleh A., Gallego O. (2007) Application of SWAT and APEX using the SWAPP (SWAT-APEX) program for the upper north Bosque River watershed in Texas. Transactions of the ASABE 50:1177-1187.

Schuol, J., Abbaspour, K., Srinivasan, R., Yang, H., 2008. Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model. Journal of Hydrology 352, 30–49.

Sillmann, J., Kharin, V. V., Zhang, X., Zwiers, F.W., Bronaugh, D., 2013. Climate extremes indices in the CMIP5 multimodel ensemble: Part 1. Model evaluation in the present climate. Journal of Geophysical Research Atmospheres 118, 1716–1733. https://doi.org/10.1002/jgrd.50203

Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society 93, 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Teutschbein, C., Seibert, J., 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies : Review and evaluation of different methods. Journal of Hydrology 456–457, 12–29. https://doi.org/10.1016/j.jhydrol.2012.05.052

Tonamo A. (2016) A review on cattle husbandry practices in Ethiopia. International Journal of Livestock Production 7:5-11.

Wang X., Kannan N., Santhi C., Potter S., Williams J., Arnold J. (2011) Integrating APEX output for cultivated cropland with SWAT simulation for regional modeling. Transactions of the ASABE 54:1281-1298.

Bürger, G., Murdock, T.Q., Werner, A.T., Sobie, S.R., Cannon, A.J., 2012. Downscaling extremes-an intercomparison of multiple statistical methods for present climate. Journal of Climate 25, 4366–4388. https://doi.org/10.1175/JCLI-D-11-00408.1

Dosio, A., Panitz, H.J., Schubert-Frisius, M., Lüthi, D., 2015. Dynamical downscaling of CMIP5 global circulation models over CORDEX-Africa with COSMO-CLM: evaluation over the present climate and analysis of the added value. Climate Dynamics. https://doi.org/10.1007/s00382-014-2262-x

Endris, H.S., Omondi, P., Jain, S., Lennard, C., Hewitson, B., Chang'a, L., Awange, J.L., Dosio, A., Ketiem, P., Nikulin, G., Panitz, H.J., Büchner, M., Stordal, F., Tazalika, L., 2013. Assessment of the performance of CORDEX regional climate models in simulating East African rainfall. Journal of Climate 26, 8453–8475. https://doi.org/10.1175/JCLI-D-12-00708.1

ESGF, 2020. Earth System Grid Federation [WWW Document]. URL https://esgf-node.llnl.gov/search/esgf-llnl/ (accessed 1.4.20).

Falkenmark, M., Rockstrom, J., 2004. Balancing Water for Humans and Nature: The New Approach in Ecohydrology. Earthscan, London, UK.

Jones, C., Giorgi, F., G. Asrar, 2011. The Coordinated Regional Downscaling Experiment: CORDEX; An international downscaling link to CMIP5. CLIVAR Exchanges 16, 15–19.

Karl, T.R., Easterling, D.R., 1999. Climate extremes: Selected review and future research directions. Climatic Change. https://doi.org/10.1023/A:1005436904097

Kim, J., Waliser, D.E., Mattmann, C.A., Goodale, C.E., Hart, A.F., Zimdars, P.A., Crichton, D.J., Jones, C., Nikulin, G., Hewitson, B., Jack, C., Lennard, C., Favre, A., 2014. Evaluation of the CORDEX-Africa multi-RCM hindcast: Systematic model errors. Climate Dynamics 42, 1189–1202. https://doi.org/10.1007/s00382-013-1751-7

Klein Tank, A.M.G., Zwiers, F.W., Zhang, X., 2009. WMO Guidelines on Analysis of extremes in a changing climate in support of informed decisions. Climate Data and Monitoring 52.

Min, S.K., Zhang, X., Zwiers, F.W., Hegerl, G.C., 2011. Human contribution to more-intense precipitation extremes. Nature 470, 378–381. https://doi.org/10.1038/nature09763

Morak, S., Hegerl, G.C., Kenyon, J., 2011. Detectable regional changes in the number of warm nights. Geophysical Research Letters 38, 1–5. https://doi.org/10.1029/2011GL048531

Nikulin, G., Jones, C., Giorgi, F., Asrar, G., Büchner, M., Cerezo-Mota, R., Christensen, O.B., Déqué, M., Fernandez, J., Hänsler, A., van Meijgaard, E., Samuelsson, P., Sylla, M.B., Sushama, L., 2012. Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. Journal of Climate 25, 6057–6078. https://doi.org/10.1175/JCLI-D-11-00375.1

Rathjens, H., Bieger, K., Srinivasan, R., Arnold, J.G., 2016. CMhyd User Manual Documentation for preparing simulated climate change data for hydrologic impact studies.

Rockstrom, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., Qiang, Z., 2010. Managing water in rainfed agriculture - The need for a paradigm shift. Agricultural Water Management 97, 543–550.

Schuol, J., Abbaspour, K., Srinivasan, R., Yang, H., 2008. Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model. Journal of Hydrology 352, 30–49.

Sillmann, J., Kharin, V. V., Zhang, X., Zwiers, F.W., Bronaugh, D., 2013. Climate extremes indices in the CMIP5 multimodel ensemble: Part 1. Model evaluation in the present climate. Journal of Geophysical Research Atmospheres 118, 1716–1733. https://doi.org/10.1002/jgrd.50203

Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society 93, 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Teutschbein, C., Seibert, J., 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies : Review and evaluation of different methods. Journal of Hydrology 456–457, 12–29. https://doi.org/10.1016/j.jhydrol.2012.05.052

Worku, G., Teferi, E., Bantider, A., Dile, Y.T., 2020. Statistical bias correction of regional climate model simulations for climate change projection in the Jemma sub-basin, upper Blue Nile Basin of Ethiopia. Theoretical and Applied Climatology 139, 1569–1588. https://doi.org/10.1007/s00704-019-03053-x

Worku, G., Teferi, E., Bantider, A., Dile, Y.T., 2019. Observed changes in extremes of daily rainfall and temperature in Jemma Sub-Basin, Upper Blue Nile Basin, Ethiopia. Theore 839–854. https://doi.org/10.1007/s00704-018-2412-x

Worku, G., Teferi, E., Bantider, A., Dile, Y.T., Taye, M.T., 2018. Evaluation of regional climate models performance in simulating rainfall climatology of Jemma sub-basin, Upper Blue Nile Basin, Ethiopia. Dynamics of Atmospheres and Oceans 83, 53–63. https://doi.org/10.1016/j.dynatmoce.2018.06.002

Worqlul A.W., Jeong J., Dile Y.T., Osorio J., Schmitter P., Gerik T., Srinivasan R., Clark N. (2017) Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. Applied Geography 85:1-13.

Annex 2. Data and publications

Datasets

1. Inventory of feed prices and quality across major feed market places in southern Ethiopia: https://doi.org/10.18738/T8/BJ0MRQ
2. Price and quality of feed resources collected from Bahir Dar zuria and other districts of Amhara region: https://doi.org/10.18738/T8/YFM43Z

Publications

Peer-reviewed publications

Abidela Hussein, M.; Muche, H.; Schmitter, P.; Nakawuka, P.; Tilahun, S.A.; Langan, S.; Barron, J.; Steenhuis, T.S (2019). Deep Tillage Improves Degraded Soils in The (Sub) Humid Ethiopian Highlands. *Land*, 8(11).

Alemie T. C., Tilhun, A. A., Ochoa-Tocachi, B. F., Schimitter, P., Buyaert, Parlange, J., & Steemhuis, (2019). Predicting Shallow Groundwater Tables for Sloping Highland Aquifers. *Water Resource Research*, 55(12).

Balasubramanya, S., & Stifel, D. (May 2020). Viewpoint: Water, agriculture & poverty in an era of climate change: Why do we know so little(pp.101905). *Food Policy*, 93.

Bayabil, H. & Dile, Y. T. Improving Hydrologic Simulations of a Small Watershed through Soil Data Integration. *Water,* 12(10).

Belay, S., Assefa, T., Prasad, V., Schmitter, P., Worqlul, A. W.... (July 2020). The Response of Water and Nutrient Dynamics and of Crop Yield to Conservation Agriculture in the Ethiopian Highlands(pp.5989). *Sustainability*, 12(15).

Belay, S. A., Schmitter, P., Worqlul, A. W., Steenhuis, T. S., Reyes, M., & Tilahun, S. A. (2019). Conservation agriculture saves irrigation water in the dry monsoon phase in the Ethiopian highlands. *Water*, 11(10).

Berihun, m. L., Tsunekawa A., Harageweyen, N., Dile, Y. T., Tsubo, M., Fenta A. A., Meshesha, D. T., Ebabu, K.,Sultan, D., & Srinivessan R. (July 2020). Evaluating runoff and sediment responses to soil and water conservation practices by employing alternative modeling approaches(pp.1-19). *Science of the Total Environment*, 747, Amsterdam, Netherlands.

Dile, Y. T., Ayana, E. K., Worqlul, A. W., Xie, H., Srinisvasan, R., Lefore, N., You, I., & Clarke N. (September 2020). Evaluating satellite-based evapotranspiration estimates for hydrological applications in data-scarce regions: A case in Ethiopia. (pp.140702.). *Science of The Total Environment*, 743.

Kadigi, I., Richardson, J., Mutabazi, K., Philip, D., Bizimana, J., Mourice, S., & Waized, B. (2019). Forecasting farm productivity and profitability as probability distributions for main cereal crops in Tanzania: a multivariate empirical (MVE) approach. *Agricultural Systems*, 180.

Kadigi, I., Mutabazi, K., Philip, D., Richardson, J., Bizimana, J., Mbungu, W., Mahoo, H., & Sieber, S. (August 2020). An Economic Comparison between Alternative Rice Farming Systems in Tanzania Using a Monte Carlo Simulation Approach(pp.22). *Sustainability,* 12(16).

Kadigi, I., Richardson, J., Mutabazi, K., Philip, D., Mourice, S., Mbungu, W., Bizimana, J., & Sieber, S. (September 2020). The effect of nitrogen-fertilizer and optimal plant population on the profitability of maize plots in Tanzania: a bio-economic simulation approach(pp.18). *Agricultural Systems*, 185.

Mwinuka, P. R., Mbilinyi, B., Mbungu, W., Mourice, S., Mahoo, H., & Schmitter, P. (September 2020). Optimizing water and nitrogen application for 1 neglected horticultural species in 2 tropical sub-humid climate areas: A case of African eggplant (Solanum aethiopicum L)(pp.109756). *Horticulture*, 276.

Ringler, C. (2020). Water for all: Making SDG 6 a reality. *Rural21*, 54(1).

Taddele, Y. D., Ayana, E., Worqlul, A. W., Srinivasan, R., Lefore, N. (July 2020). Evaluating satellite-based evapotranspiration estimates for hydrological applications in data-scarce regions: a case in Ethiopia (pp.1-22). *Science of the Total Environment*, 743.

Tilahun, S. A., Yilak, D., Schimitter, P., Zimale, F. A., Langan, S., Barron, J., Parlange, J., & Steemhuis, T. S. (2020). Establishing irrigation potential of a hillside aquifer in the African highlands. *Hydrological Processes*.

Tilashwork, A. C., Tilahun, S., Ochoa-Tocachi, B. F., Schmitter, P.,Buyaert, W., Parlange, J., & Steenhuis, T. (December 2019). Predicting Shallow Groundwater Tables for Sloping Highland Aquifers(pp.11088). *Water Resource Research*, 55(12).

Worqlul, A. W., Dile, Y. T., Jeong, J., Adismassu, Z., Lefore, N., Gerik, T., Srinivasan, R., & Clarke N. (2019). Effect of climate change on land suitability for surface irrigation and irrigation potential of the shallow groundwater in Ghana. *Computers and Electronics in Agriculture*, 157.

Worqlul, A. W., Dile, Y. T., Schmitter, P., Jeong, J., Meki, M., Gerik, T., Srinivasan, R., Lefore, N., & Clarke N. (September 2019). Water Resource Assessment, Gaps, and Constraints of Vegetable Production in Robit and Dangishta Watersheds, Upper Blue Nile Basin, Ethiopia. *Agricultural Water Management*, 226.

Discussion/Working Papers and reports

Balana, B. & Appoh, R. (August 2019). Assessment of private actor participation in the irrigation technology supply chain: Ghana case study. IWMI, Accra, Ghana

Bryan, E., Mekonnen, D., & Hagos, F. (July 2020). The diffusion of small-scale irrigation technologies in Ethiopia: Stakeholder analysis using Net-Map. Washington DC: IFPRI.

Bryan, E. (2020). What does empowerment mean to women in northern Ghana? Insights from research around a small-scale irrigation intervention. IFPRI Discussion Paper, 1, Washington DC: IFPRI.

Lefore, N., Hagos, F., Gelgo, B., & Haileslassie, A. (August 2019). Rapid assessment of the agricultural water management technology supply chain: Ethiopia case study. IWMI, Addis, Ethiopia

Mekonnen, D. (2019). Irrigation-nutrition linkages: Evidence from northern Ghana. IFPRI Discussion Paper, 1887, Rome, Italy: IFPRI.

Xie, H., Olayide, O., Alkassoum Sangaré, S., & Koo, J. (September 2020). Targeting Small-Scale Irrigation Investments using Agent-Based Modeling: Case Studies in Mali and Niger. Bonn, Germany.

Conference papers and posters; Presentations

Bizimana, J., Richardson, J.W., Bryant, H., Herbst, B.K., Clarke, N.P., Dile, Y.T., Lefore, N., Gerik, T.J., Srinivasan, R., & Worqlul, A.W. "Economic and Nutrition Impacts of Irrigated fodder in Lemo woreda-Ethiopia". 2020 Carter Conference at University of Florida, April 15-17, *2020 (accepted; event cancelled)*

Dile, Y., Ayana, E.K., Worqlul, A.W., Xie, H., Bizimana, J., You, L. Lefore, N., Gerik, T., & Clarke N. "Estimating blue and green water resources availability in Ethiopia". American Geophysical Union (AGU) Meeting, December, 2019 in San Francisco, California.

IFPRI, "Last Mile Energy Access for Productive Energy Use in Agriculture in Sub-Saharan Africa – What and Where is the Potential?" American Geophysical Union Meeting, December, 2019 in San Francisco, California.

IWMI. "Dynamics of small scale irrigation development: Subsidizing and capitalizing pathway of scaling" presented at the 2nd International conference on 'Irrigation and Agricultural Development, at University for Development Studies (UDS), 25th to 27th February 2020 in Tamale, Ghana.

Lefore, N. (2019). "Applied research and models: Scaling agricultural water management in Sub-Saharan Africa". American Geophysical Union (AGU) Meeting, December, 2019 in San Francisco, California.

Lefore, N., Taddele, Y. D., Worqlul, A. W., Srinivasan, R., Gerik, T. (2020). Economic and Nutrition Impacts of Irrigated fodder in Lemo woreda-Ethiopia. Presentation at Agricultural & Applied Economics Association (AAEA), Kansas City, MO.

Richardson, J., Henry, B., Derseh, M. B., Worqlul, A. W., Taddele, Y. D.... (August 2020). Economic and nutrition impacts of irrigated fodder and crossbred cows on households in Lemo woreda-Ethiopia. Presentation at Agricultural & Applied Economics Association (AAEA), Kansas City, MO

Ringler, C. (2020). Approaches to Strengthening Climate Resilience, Gender and Nutrition through Integration: Insights from the GCAN and ILSSI projects. Presentation at IWMI hosted seminar, Accra, Ghana.

Ringler, C. (January 2020). Approaches to Strengthening Climate Resilience, Gender and Nutrition through Integration: Insights from the GCAN and ILSSI projects. Presentation at IWMI hosted seminar, Accra, Ghana.

Ringler, C. (June 2020). Harmonizing Actions on Water and Nutrition within the United Nations. Presentation at American Society of Nutrition, Virtual.

Worqlul, A.W. (2020). "Nutrition potential of fodder and constraints of fodder production with small-scale irrigation systems in Ethiopia". 2020 Carter Conference at University of Florida, April 15-17, 2020 *(accepted; event cancelled)*.

Outreach/Engagement

Balasubramanya, S., Schmitter, P., & Minh, T. T. (April 2020). Scaling farmer-led irrigation in sub-Saharan Africa: What does it take? IWMI Technical Brief.

Fry, C. (August 2020). Debating how to nurture sustainable and inclusive farmer-led irrigation. IWMI -DWFI- GWP.

Fry, C. (June 2020). Experts unite to find the best ways to scale up farmer-led irrigation. IWMI - DWFI-GWP.

IFPRI - International Food Policy Research (August 2020). WASAG: Actions for Water and Nutrition Security

Lefore, N. & De La Salle Tignegre, J. (June 2020). Vegetable seed development in Mali: Assessing opportunities for irrigated seed production to improve nutrition amid climate risks and water insecurity Webinar, Agrilinks.

Patel, P. (June 2012). How to accelerate and scale inclusive water access in Ethiopia. IWMI.

Patel, P. (August 2020). Initial Research Highlights Importance of Irrigation for Ethiopian Farmers During COVID-19. Agrilinks.

Schmitter, P. & Minh, T. T. (June 2012). Private sector joins multi-stakeholder dialogues on farmer-led irrigation development in Ghana and Ethiopia. ILSSI.

Papers under review and/or accepted

Atuobi-Yeboah, A.. Smallholder Irrigation Technology Diffusion in Ghana: Insights from Stakeholder Mapping

Balana, B. & Appoh, R. (2019). Assessment of private actor participation in the irrigation technology supply chain: Ghana case study. IWMI, Accra, Ghana

Clarke, N. & Richardson, J. (2017). Household Food Security and Nutrition Analysis Using a Farm Simulation Model (FARMSIM): Case Study of Ethiopia. *Journal of Agriculture and Food Research*

Fenta, H., Hussein, M., Tilahun, S., Nakawuka, P., Steenhuis, T..... Berken plow and intercropping with pigeon pea ameliorate degraded soils with a hardpan in the Ethiopian highlands. *Soil & Tillage Research*

Haile, B. (2019). Determinants and constraints of small-scale irrigation in Sub-Saharan Africa: An econometric analysis. *Water International)*

Lefore, N., Taddele, Y. D., Worqlul, A. W., Srinivasan, R., Gerik, T., Haimanote, B, Ayana Essayas. Evaluating the value of spatial data resolution to improve biophysical simulations. *Catena*

Mekonnen, D. Irrigation improves WHZ-scores of children under five, WDDS, and HDDS in Ethiopia and Tanzania, with stronger effects in households who reported drought shocks. *Journal of Nutrition*

Mekonnen, D. Seasonal variation in maternal dietary diversity is reduced by small-scale irrigation practices: a longitudinal study. *The American Journal of Clinical Nutrition*

Minh, T. T., Cofie, O., Lefore, N., & Schmitter, P.. Multi-stakeholder dialogue space on farmer-led irrigation development: An instrument driving systemic change with private sector initiatives. *Knowledge Management for Development Journal*

Mwinuka, P. R., Mbilinyia, B., Mbungu, W., Mourice, S., Mahooa, , & Schmitter, P.. The feasibility of hand-held thermal and UAV-based multispectral imaging for canopy water status assessment and yield prediction of irrigated African eggplant (Solanum Aethopicum L). *Agricultural Water Management*

Ringler, C., Mekonnen, D., Balana, B., Hagos, F., Haile, B., & Yimam, S. (September 2020). Credit constraints and small-scale irrigation technology adoption: Evidence from Ethiopia and Tanzania. IFPRI hosted brownbag

Tesfaye, M., Daba, T., Balana, B., & Gebregziabher, *G.*. Adoption constraints and smallholder farmers' willingness to pay for irrigation water lifting technologies: Evidence from Ethiopia. *Journal of Rural Studies*

Taddele, Y, Bayabil H., Ayana E., Worqlul a., Srinvasan R., Gerlik T., Lefore L., Clarke N. Evaluating the Value of Spatial Data Resolution to Improve Biophysical Simulations. *Catena*

Worku, M. & Adie, A. (September 2020). Potentials of hybrid Brachiaria grasses as a source of good quality fodder in the Ethiopian highlands. The Joint International Grassland and International Rangeland Congress, Kenya

Worqlul, A. W., Assefa, T., Jha, M., Reyes, M., & Tilahun, S. Conservation Agriculture with Drip Irrigation: Effects on Soil Quality and Crop Yield in Sub-Saharan Africa. *Journal of Soil and Water Conservation.*

van Biljon, C.. Does Small-Scale Irrigation improve WASH outcomes? Insights from rural Ethiopia

Xie, H. Solar or Diesel: A Comparison of Costs for Groundwater-Fed Irrigation in Sub-Saharan Africa Under Two Energy Solutions. *Environmental Research Letters*

Annex 3. Preliminary results from fodder value chain analysis

Overall, farmers awareness on proper feeding, storage, and management of crops residue is low, resulting in poor quality of this feed and feeding practices. Hence, interventions are needed to remedy this problem and promote proper feeding, improve quality, and storage mechanisms. One way to do this could be provision of trainings (soft skills) to farmers on roughage feed treatment and better storage methods.

Feed wastage and bulkiness during feeding of crops residue are serious problems in both sites particularly in the stall feeding system. Interventions and closer attention are required in order to manage feed waste and improve the palatability of roughage feeds. Promotion of feeding trough and other feed management technologies could be used to address the issue.

Generally, the awareness of farmers on the importance and utilization of improved fodder is low. This category of feed is rich in nutrition values and highly important for dairy production. Hence, interventions to improve farmer awareness and the use of improved fodder feed are required. One option could be to promote smallholder fodder cultivation using small-scale irrigation technologies.

Although woreda stakeholders like livestock experts and extension workers have general training on livestock production, they lack awareness and tacit knowledge on feed and forage development. Therefore, targeted training on the following feed and forage development issues should be given to strengthening the capacity of stakeholders:

- Forage seed business models,
- Improved fodder production modality,
- Irrigation technologies,
- Forage packages, and
- Modern extension systems.

Lack of access to improved forage seeds is the key problem in the input supply segment of the feed value chain. Interventions are needed to alleviate this problem and enhance supply of quality forage seeds to farmers. One option could be organizing farmers into forage seed producer groups and support the groups in seed production and marketing. This also helps to improve farmer livelihoods from the seed business (sell of forage seeds).

Women collective action (e.g. women forage seed business association) – support the association to engage in improved fodder seeds production and marketing.

Supply of improved forage seeds – (direct supply) provision of forage seeds and planting materials to farmers.

Long AIBP and formulated feed value chains and low quality of AIBP purchased from retailers as the retailers do not have enough knowledge on this issue. The long supply chain resulted in high transaction costs and increased unit price. Hence, interventions are required to remove the middlemen and increase supply of AIBP. One way could be through supporting and facilitating the engagement of youth entrepreneurs in the distribution and marketing of AIBP. This could also create job opportunities for the youth and help to reduce the rapidly growing youth unemployment in the regions.

Dairy cooperatives play a pivotal role in linking farmers to remunerative urban dairy markets in both sites. However, they are confronted with problems of internal governance (low member participation, commitment problem, weak leadership, lack of awareness on cooperative business model) and management problems. Hence, interventions are required to enhance the service delivery performance and organizational capacity of the dairy cooperatives. This could be improved through:

- Provision of trainings to leaders/managers on management of cooperative, cooperative business models, and leadership
- Awareness creation and training of members on cooperative functions, bylaws, and governance
- Facilitate capacity building through provision of milk processing equipment, storage, and office facilities

Annex 4. Success stories

Collaboration with Livestock and Fisheries Sector Development project

Location: Bahir Dar, Amhara region

Livestock and Fisheries Sector Development (LFSD) project is a World Bank funded national project under the ministry of agriculture, which operates across the four major regions of Ethiopia (Amhara, SNNPR, Oromia and Tigrai regions). In the Amhara region, the project operates in 15 districts (Woredas). Bahir Dar Zuria district is one of the project sites for this project and overlaps with the ILSSI operational site. The project aims to develop the livestock and fisheries value chain in the regions and develop market networks for livestock inputs and produces. The project works explicitly on fodder development and strengthening the capacity of farmer interest groups (cooperatives). ILSSI irrigated fodder team have approached them and conducted fruitful discussions on how to work together to scale irrigated fodder technologies through their project. After visiting the ILSSI project sites in Robit Bata kebele, they were highly interested to take the experiences/success they have seen to other kebele's through their financial support. LFSD coordinators wanted to scale the fodder cultivation practice and housing that ILSSI was promoting (specifically feed troughs) to other kebeles. Aiming for that LFSD district coordinators selected and sent representative development agents and lead farmers (carpenters) to attend the training that ILSSI had organized for the Robit Bata kebele cooperative members. LFSD have funds for forage seed purchases to distribute to the different districts. In the future, the cooperatives which will be supported by ILSSI to engage in seed multiplication can partner with the LFSD to supply forage seeds. The collaboration between ILSSI and LFSD creates a good opportunity and would continue on different areas including capacity development, technical advices, and promotion of irrigated fodder production, marketing and proper utilization practices.

After the training, LFSD were able to scale the new technologies eight different kebeles/villages in Bahir Dar zuria district.

Scaling of irrigated fodder production practices

Location: Bahir Dar zuria; Lemo and Durame districts

By closely working with national partners, site-based research associates were able to coordinate and support farmers who showed interest in irrigated fodder production during the months of June and July. A total of 338 farmers were identified and provided with improved forage planting materials in the period. The new farmers were able to allocate a plot of land ranging from 100 to 400 square meters each for irrigated fodder production, covering approximately 6 ha of land with irrigated fodder crops. More number of farmers showed interest in piloting the new practice, however, due to the movement restrictions, it was not possible to satisfy the demand of all farmers. This was considered as good progress as the awareness of farmers on small scale supplemental irrigation increased considerably over time.

Irrigated fodder production and improved livestock productivity empower rural women in Ethiopia

In Ethiopia, mixed crop-livestock farming is the dominant source of livelihood for farmers in rural areas. The livestock sub-sector provides employment opportunities to more than 70% of the rural population, and accounts for about 46% of the country's agricultural gross domestic product. Despite the economic and livelihood potentials of this sub-sector, productivity has remained suboptimal and a shortage of good quality feed for year-round feeding remains a major challenge. The problem usually becomes severe in the long dry season when animals have limited options rather than poor quality crop residues.

In rural Ethiopia, culturally, women and children are responsible for taking care of animals kept around the homestead including sourcing feed, preparing and bringing feed to the animals, milking, and cleaning barns. Collecting adequate feed for livestock and bringing it to the animals usually takes much of the time and workload in rearing livestock particularly during the dry season. Production of irrigated fodder around the homestead would undoubtedly improve the availability of good quality feed at the household level, which has the potential to reduce the time spent looking for feed but also increase milk yield.

To address this gap, the Innovation Lab for Small Scall Irrigation (ILSSI) irrigated fodder project has implemented a series of demonstrations, validations, and trainings to enable smallholder farmers to utilize small scale irrigation technologies to produce good quality fodder on-farm that would help them bridge dry season feed shortages, improve livestock productivity, and increase their income. The project works with men and women farmers organized in cooperatives to promote the uptake of the technology and develop the value chain. After few years of work, farmers' awareness about the potentials of irrigated fodder cultivation increased, and the number of farmers adopting the practice in the project sites expanded from less than 20 farmers 5 years ago to more than seven hundred recently. Simultaneously, the area covered with irrigated fodder increased due to expansion of already established plots and adoption by a new group of farmers. The developments were quite interesting as some farmers were found to expand their fodder plots by replacing part of the land they allocated for other crops, including *Khat*, a narcotic plant that they use as a cash crop. The intervention has helped to strengthen farmer dairy cooperatives, which work to create a reliable market network for milk, forage seeds and irrigation technologies. The ILSSI project has also introduced improved feed troughs and feed choppers which were also found to save feed wastages while feeding by more than 30% and increase feed intake of animals with a direct positive effect on animal productivity. These technologies clearly demonstrated improvement in the way livestock are reared by smallholder farms.

Ensuring that the interventions provide greater opportunity for women to have a better access to and control over farm resources is very important. To that end, the ILSSI irrigated fodder project has initiated a gender analysis study for the irrigated fodder value chain to quantitatively establish the contributions of irrigated fodder technologies in empowering rural women, enhancing their livelihoods and building climate resilience. While the results of the broader study are to inform the development and scaling of the new production practices, we interviewed 4 women farmers to share with us their experiences in engaging in irrigated fodder production.

Figure 1. Farmer Mulu Melese, Kededa Gamela district (Photo Credit; Tigist German)

Mrs Mulu Melese is a married farmer living in Zato Shodera village located in Kededa Gamela district in the southern region of Ethiopia.. She has been producing irrigated fodder for seven years now after receiving training and planting materials from the project and the local extension. She recalls the time she started producing fodder and says at the time she had lactating cows but was unable to feed them adequately due to lack of good quality forage on-farm. She used to buy concentrate mixes from a nearby market to supplement the diet of the cows, but prices of concentrates continued to increase and became very expensive and unaffordable. She recounts that although she owned two lactating cows, they were unable to produce enough milk for her family and for sale. When she heard about the opportunity to get training and planting materials of improved fodder, she became highly interested and approached the extension agents. She is now actively engaged in producing irrigated fodder and feeding her lactating cows. She says her husband supports the fodder production by ploughing the land and preparing it well for planting. She is mainly responsible for irrigating the plots in the backyard by fetching water from a nearby spring, feeding and milking cows. Mulu recalls the benefits the family obtained from the fodder cultivation and feeding to lactating cows. She already had crossbred cows and when the animals were fed with the good quality green fodder the milk production almost doubled immediately, which subsequently increased the income, nutrition and living condition of the family. At the moment she is happy with the progress she has made. When asked about her future plans, she aspires to expand her fodder plot and engage more on milk production. However, she cites shortage of labor as a constraint saying her family labor is limited and hiring external labor is expensive and often unavailable. When asked what advice she would give to fellow farmers who are not growing fodder, she said, "I have been sharing my experiences to men and women farmers and, over the last couple of years, I has given fodder planting materials to more than 48 farmers for free. I advise women farmers to improve their income from the sale of milk and milk products by upgrading their local cows and adopting improved irrigated fodder cultivation practices".

Figure 2. Farmer Tewabech Belayneh (Photo Credit: Tigist German)

Mrs Tewabech Belayneh is married farmer living in Zato Shodera village, located in Kededa Gamela district, in southern Ethiopia. She started fodder cultivation five years ago when she received training and planting materials from the project. When asked what motivated her to start the new practice, she recounted the time when the income that her husband obtained from his employment was very low and the family were unable to meet their daily subsistence and school fees for children. As a result, she thought about starting her own income generating activity, and when she was invited to join the group engaged in fodder cultivation, she was more than happy to be involved. Both she and her husband devote time to fodder cultivation, with the husband helping her prepare land, hoe the fodder plots and harvest the fodder, while she is mainly responsible for irrigating the fodder plots, adding manure and other fertilizers, milking cows and handling the milk. During the first two years of fodder cultivation, Tewabech generated income mainly by selling the green fodder in the local market. Eventually, their income improved and managed to buy a heifer. Now the heifer grew up and gave birth to a calf, allowing her to produce milk by feeding the fodder she produces. Currently she also buys supplemental concentrate from the market to improve the nutrition of her cow and increase the milk yield. Tewabech says the fodder cultivation practice that she started a few years ago paid her back very well, and she feels satisfied with what she achieved. She plans to expand both her dairy farm and fodder plots in the future. When asked the main challenge she faces now, she says finance is the main constraint indicating that the price of crossbred heifers and cows has become beyond the capacity of ordinary farmers. When asked what her advice to fellow women, she says she continues to share her experiences how her family life changed due to fodder cultivation and dairy farming. She tries to teach her neighbors how to feed and handle dairy cows. As a result, she says, "you don't find a household in my vicinity which doesnot cultivate fodder now"

Figure 3. Farmer Wubejig Andarge, Bahir dar zuria (Photo credit: Fikadu Tessema)

Mrs. Wubejig Andarge is a farmer in Robit Bata village, Bahir Dar zuria district in the Amhara region of Ethiopia. Her family started producing irrigated fodder after the ILSSI project and Andassa research center nominated her for training and demonstration of improved fodder cultivation. She remembers she started producing irrigated Napier grass, Desmodium, and Sesbania on a small plot in 2017. When her family saw that the fodder had contributed considerably to meeting their livestock feed demands, they expanded their plots gradually and now they have close to one-fifth of a hectare irrigated fodder plot. In the meantime, she also received a crossbred cow from Andassa research center. Now she believes she has the right type of animals to feed her good quality fodder and the milk they produce increased from tow to almost five liters per day per cow, which is enough for own consumption and sale. She now regularly supplies milk to the dairy cooperative. She cites the unavailability of quality forage seed and land shortage as a major constraint to expand the technology in her community. The demand for seeds and planting materials is increasing and she advises fellow farmers to start with small plots and produce their planting materials to expand gradually.

Useful Links

https://www.ilri.org/research/programs/feed-and-forage-development

https://www.ilri.org/news/irrigated-forages-improve-livestock-productivity-and-livelihoods-ethiopia

https://scholar.google.com/citations?user=YjLk04IAAAAJ&hl=en

Figure 4. Farmer Mogninet Fentea, Bahir Dar zuria district (Photo credit: Fikadu Tessema)

Mrs. Mogninet Fentea is married a and lives in Robit Bata village in Bahir Dar zuria district of the Amhara region. She and her husband started irrigated fodder production in 2017 after she received support from the project and the local extension staff. The training they got, and the demonstrations they saw convinced them to start trying the new practice. At the time, they were facing a serious feed shortage during the dry season for their lactating cows and draft oxen. Since the beginning of fodder cultivation, they saw a steady improvement in the productivity of their animals, cows giving more milk, and draft oxen becoming in a good condition during the time of land preparations. As a result, their household income increased, and they were able to cover their children's school expenses relatively easily. She remembers, she and her husband decided to expand their fodder plot by uprooting some of the Khat plants they grow because they were convinced that the fodder is important for the household. Mogninet explains that the feed trough they constructed for their cattle helped them save labor and feed. They cut, chop and place the green fodder in the feed trough mixed with other local feed resources and leave animals to feed and rest without a need for frequent observation by the family. That has helped the children to spare time to concentrate on their learning. Now Mogninet says they are adapting well to a cut-and-carry feeding practice in their household. Recently, they also got a solar pump, which has eased their water lifting and irrigation work. Her neighbors have become interested in the new practices and regularly visit their plots.

Figure 5. Mogninet's family farm and feed trough

Impacts and Looking Ahead

The women interviewed witnessed an improvement in livestock productivity and their livelihoods as a result of the new practices. An important observation from the response of the farmers is that most of them feed the fodder they cultivate to lactating cows to increase milk yield. This has a clear gender and household nutrition implications. Traditionally, women are the ones who handle the milk produced and manage the income generated from this activity. While they regularly supply fluid milk to the cooperative, part of the milk is usually processed by the women into butter, cheese, and buttermilk. The butter is partly sold to generate income, but the cheese and buttermilk are wholly consumed by the household, which contributes to the nutrition of the households. The gendered norms, roles, and responsibilities within livestock value chains present challenges, as well as opportunities, for female farmers to acquire and apply new technologies and knowledge for enhanced forage production. Therefore, it can be concluded that irrigated fodder and dairying is an important entry point to empower women in the smallholder systems and build their climate resiliences to improve their livelihoods. In the fodder cultivation process, women are mainly involved in fetching water and irrigating fodder plots. In other words, women retain their socially ascribed roles that are time and labor demanding. Technologies that save labor to extract water from shallow wells/streams, as well as forage varieties that require minimum water and nutrient input would help to reduce the workload on women and demands on their time, while also improving their livelihoods. Helping women access improved breeds of livestock with good feed utilization traits is critical for the technology to be lucrative and sustainable. ILSSI is trying to address these issues by demonstrating alternative water-lifting technologies, including solar pumps as well as fodder species/varieties. The project is also closely working with dairy cooperatives and national partners to strengthen the forage seed system and develop the fodder value chain. The project tries to address gender inequalities that reduce smallholder systems' resilience and prevent women from accessing business opportunities.