Discussion Paper

Feed the Future Innovation Lab for Small-Scale Irrigation: Ethiopia

Discussion Paper for Stakeholder Consultation
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Assessments of key small-scale irrigation technologies, agricultural water management options and integrated irrigated fodder in Ethiopia

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1. Introduction

1.1 Problem setting

Agriculture is the mainstay of the Ethiopian economy. It accounts for more than 46% of the national GDP. Subsistence rain-fed systems dominate Ethiopia's agricultural landscape due to erratic rainfall and poor access to supplementary irrigation. As a result, crop production, the major contributor to the agricultural economy, is underperforming. Single cropping is the norm but double-cropping is practiced along rivers in some parts of the country. The potential of irrigable land in Ethiopia is between 3.7 and 4.3 Mha, but only 7 to 10% of the potential is currently irrigated (MoARD, 2009). This present situation contrasts with the country's longstanding tradition of small-scale irrigation (SSI). Small-scale irrigation is usually developed privately by farmers in response to family and local market requirements. Farmers dig, dam or divert to deliver water to systems, farm plots and plants. It is widely argued that lack of location specific suitable irrigation technologies, management systems and evidence-based decisions are key constraints to revitalizing this important sector of the Ethiopian agricultural economy.

In most parts of Ethiopia rainfall distribution is extremely uneven both spatially and temporally. Drought frequently results in crop failure, while high rainfall intensities result in low infiltration and high runoff, causing soil erosion and land degradation. This in turn contributes to low agricultural productivity and high levels of food insecurity. Over the past two decades, the Government of Ethiopia has attempted to address these issues through the large-scale implementation of a range of soil and water conservation measures including: stone terraces, soil bunds and area enclosures. Despite these efforts, adoption of the interventions remains low. Studies on the Ethiopian Highlands show that the adoption of rainwater management technologies is influenced by a variety of factors, including biophysical characteristics, such as topography, slope, soil fertility, rainfall amount and distribution (Gebregziabher et al., 2013a).

Experiences show that rainwater harvesting technologies, using soil as a "water tank", are more effective when soil water holding capacity is large enough. In addition to the nature of the soil itself, soil crusting and compaction are common soil management-related problems and most often attributed to tillage practices that lead to the development of plough pans and thus limiting soil water storage capacity (Hatibu and Mahoo, 1999). Previous research results (Hudson, 1987) have shown that deep tillage is an important factor in controlling soil moisture characteristics, because it reduce surface sealing of the soil and permits roots proliferation to exploit water and soil nutrients at deeper soil horizons. Likewise, Hatibu and Mahoo (1999) reported significant and positive correlation between crop yields and depth of tillage in Hombolo, Central Dodoma in Tanzania.

However, even when technologies are appropriate to a particular biophysical setting, they may not be implemented due to a variety of social factors farmers consider when adopting land and water management technologies. In general, farmers are more likely to adopt a combination of agricultural water management (AWM) technologies as a coping mechanism against climate variability and agricultural production constraints when technologies are context specific. In Tigray, for example, farmers apply both rainwater harvesting technologies and groundwater irrigation by accessing shallow groundwater sources found in most valley floors of treated catchments (Woldearegay and Steenbergen, unpublished).

Similar to the crop production, livestock is an important avenue to improve livelihoods for smallholder farmers in Ethiopia. Although the proportional contribution of livestock and crops fluctuates from year to year, livestock contributes more than 22% of the agricultural GDP and shares a significant proportion of total export revenue [Netherlands- Africa Business Council (NABC, 2010)] in Ethiopia. Smallholder farmers in the midland and highland areas practice mixed farming systems where livestock and crop production are highly integrated, while in the lowland areas, pastoral systems dominate (AgWater Solutions, 2010; Weight et al., 2013).

With increasing trends in demand for livestock products, both globally and locally, more opportunities are foreseen and the role of livestock in the livelihood of the majority of smallholder farmers will likely increase. However, these opportunities are highly constrained by shortage of sufficient and quality feed resources (Blummel et al., 2009; Blummel, 2000). Generally feed is an interface between crop and livestock production (Haileslassie et al., 2012; Blummel et al., 2009). Emerging evidence suggests that linking 'system-components' (e.g. *crop vis a vis livestock*) enables better resource use efficiencies including water use efficiency and food security. When resources flow between livestock and crop compartments, water productivity and financial return are improved (Erkossa et al., 2014).

1.2. Background and Objectives of the Discussion Paper

Recognizing the relationships and multi-dimensionality of the system, the United States Agency for International Development Feed the Future (FtF) support for Small Scale Irrigation (USAID–SSI) in Ethiopia, Tanzania and Ghana plans to identify, test and demonstrate technologies, and promote dialogue on research evidence among the stakeholder community and policy makers. To this end, a consortium led by the Texas A&M University System will bring together the International Water Management Institute (IWMI), the International Livestock Institute (ILRI), the International Food and Policy Research Institute (IFPRI) and North Carolina A&T State University to collaborate with national partners to: (1) identify promising small-scale irrigation technologies (including integration of fodder production), practices and strategies that have the potential to improve agricultural productivity, reduce farmer risks, improve nutritional quality and diversity, reduce poverty, and empower women farmers; (2) demonstrate and assess the feasibility of promising solutions; (3) develop context specific recommendations of technologies and strategies to improve access to irrigation technologies and agricultural water management options; and (4) train agricultural and development students, educators, and professionals to analyze the farm- and watershed-level biophysical, economic, nutritional and labor implications of these technologies and strategies. The project will build on the experience of [1]AgWater Solutions and other projects.

Towards meeting the above objectives, the project adopts a continual engagement approach with stakeholders. As an initial step in the project, a stakeholder consultation is to be held in each country, with the first to be in Ethiopia, followed by Ghana and Tanzania. This paper is intended as the basis for discussion at the stakeholder consultation, and provides an input to consultations. The first section in the discussion paper summarizes lessons from previous and ongoing IWMI- and ILRI-led projects. That is followed by brief outlines of potential interventions for agricultural water management and integrated

[1] For more information on the AgWater Solutions project and research results, see: awm-**solutions**.iwmi.org/

irrigated fodder. The final section of the paper lists the potential interventions for further discussion amongst stakeholders. With this discussion paper as a starting point, the objectives of the stakeholder consultation include:

1. **To share experiences and lessons on promising small-scale agricultural water management and fodder integration opportunities in Ethiopia**
2. **To review, discuss and propose potential water delivery and management technologies for small scale irrigation in Ethiopia that may be field-tested and piloted under the ILSSI project**
3. **To review, discuss and propose potential irrigated fodder technologies for smallholders in Ethiopia that may be field-tested and piloted under the ILSSI project**

2. Lessons from Other Projects

2.1. Lessons from the AgWater Solutions Project

The AgWater Solutions project (funded by the Bill & Melinda Gates Foundation and led by IWMI) aimed to identify investment options and opportunities in agricultural water management with the greatest potential to improve incomes and food security for poor farmers, and to develop tools and recommendations for stakeholders in the sector including policymakers, investors, NGOs and smallholder farmers. The three-year project, which concluded in 2012, was implemented in five countries in Africa, including Ethiopia, and two states in India. Within each country, the project followed a common methodology to identify promising agricultural water management options and their potential for up-scaling nationally and regionally (Box 1). Key findings from the AgWater Solutions and other small-scale irrigation projects are presented here to support the stakeholder discussion.

Based on the preliminary situation analysis and stakeholder consultation of Agricultural Water Management (AWM) practices in Ethiopia (AgWater Solutions, 2010), a set of AWM options were identified to be technically feasible, affordable and practical for smallholder farmers. The technologies identified included community-based watershed management, water-lifting technologies, groundwater use for agriculture and manual well drilling, cost-benefit analysis of investment in groundwater irrigation, on-farm water storage, small reservoirs and rainwater harvesting technologies. We summarize below the key findings from the field and watershed level analyses and national scale mapping of the potential for smallholder AWM in general and these aforementioned technologies in particular.

Box 1. AgWater Solutions approach

Situation analysis and selection of AWM options: An initial analysis was undertaken of the conditions in each country and the AWM practices already in place. These were reviewed with stakeholders and some of the most promising practices were selected.

Field-scale and community-level case studies: A participatory opportunity and constraint analysis and methodology was applied to understand the complex interaction among social, economic and physical factors that influence the uptake and success of AWM options, and to identify technologies appropriate to different contexts in each of the project countries.

Watershed-level case studies: A multi-disciplinary approach was used to understand how watershed management contributes to livelihood improvement of smallholder farmers and factors that contribute to the success of watershed management.

National AWM mapping: Maps were developed to assess 1) where AWM will have the greatest impact within a country and where specific interventions will be most viable; 2) the potential for investment in water to support rural populations was mapped based on demand and availability of water; and 3) the suitability and demand for specific AWM interventions and the estimated potential number of beneficiaries, application area and investment costs.

Regional AWM analysis: The regional potential for the 'best-bet' AWM technologies in South Asia and sub-Saharan Africa was assessed in terms of: potential application area, number of people reached, net revenue derived and water consumption. Scenarios were also developed to factor in climate change and potential changes in irrigation costs.

Stakeholder engagement and dialogue: A dialogue process was used to ensure that project results reflected stakeholder perceptions and addressed their concerns. National consultations, dialogues, surveys and interviews were fed into all stages of the project.

Note: see Evans (Ed.), 2012 for further details regarding the application of the project methodology in Ethiopia and summary of results.

2.1.1. Watershed Management

A study (AgWater Solutions Project, 2012a) was carried out in six community-managed watersheds (two watersheds each from Tigray, Amhara and Oromia regions). Although the success rates differ from region to region, a range of rainwater harvesting works, such as soil and water conservation activities were implemented and complement watershed management measures. The study reviewed past and present watershed management approaches and assessed factors that influence the performance of watershed management programs with a focus on assessing the upstream and downstream linkages of watershed management and its implication for agricultural water management.

The results suggested that a 'one size fits all' approach does not work, but rather context-specific watershed development solutions should be identified. Capacity building in managing watershed externalities within and outside the watershed requires cooperation among various stakeholders to build and strengthen institutions and regulations, and to develop systems of sharing responsibilities and benefits. Policy solutions to address land tenure and community rights on watersheds were also proposed.

2.1. 2. Water Lifting Irrigation Technologies

A household level survey approach was used to identify factors that influence adoption of water lifting technologies by smallholder farmers in four regions (Amhara, Oromia, SNNP and Tigray). The study (Gebregziabher, 2011) hypothesized that smallholder farmers can play a significant role in irrigation development at low cost and much higher efficiency provided they have access to appropriate water lifting technologies.

The study found that adoption rates of smallholder irrigation technologies (such as motor pumps) are low where there is a combination of technical and socio-economic factors combined with weak public support systems. Since irrigation technologies do not stand alone, the type of water source often influences the type of water lifting technology smallholder farmers may adopt. However, information about the potential of surface and groundwater sources is scant. In the absence of such information, smallholder irrigation technologies usually spread spontaneously and in an unregulated manner, posing issues of resource depletion and sustainability and increasing the risk of conflicts between users.

The study also found low level of productivity and efficiency in smallholder irrigated systems, due to highly fragmented and inefficient input and output markets. Poor supply chains; low quality of pumps; limited choice; and high taxes combined with lack of information and knowledge on irrigation, improved seeds, and lack of infrastructure have resulted in inefficient input markets. Output markets are generally dominated by middlemen, who exercise excessive power in setting market prices. This, combined with weak maintenance and extension services, place smallholder farmers at a significant disadvantage.

Issues of equity are also a key issue for women and poorer farmers. The study found that the majority of motor pump users were male and better-off farmers. Moreover, high upfront investment costs coupled with absence of financing tools, limited access to credit and marketing information are likely to widen the gap between men and women and poor and better-off farmers.

2.1. 3. Assessment of Opportunities and Constraints of Groundwater Use

A study by the AgWater Solutions Project (AgWater Solutions Project, 2012b) examined the potential of groundwater availability, groundwater technologies, and status of the groundwater use for agricultural production, institutions and direction of future groundwater utilization for agriculture. The study was based on a comprehensive review of literature and groundwater data available from regional state water bureaus. It described the geological succession and aquifer types of the country, groundwater potential and its utilization, policies and institutions of groundwater development, human resources and knowledge gap in relation to groundwater development and groundwater drilling technologies.

In Ethiopia, the development of groundwater for small-scale irrigation has gained prominence more recently. The Growth and Transformation Plan (GTP), for example, emphasizes the use of shallow wells for agricultural production, but the uptake of groundwater irrigation remains low. A number of factors, such as high cost of well construction, limited capacity in well drilling and underdeveloped markets for high value irrigated crops appear to constrain adoption of groundwater irrigation. Moreover, the institutional framework that governs groundwater development and its use is not clear. For example, the government is the main driver for the development of small-scale irrigation with heavy top-down pressure. Although a role exists for government involvement, especially at initial stages of groundwater development, this has to be turned into opportunity to create strong private sector engagement. For example, a 'smart subsidy' approach where private businesses act as agents for smallholder farmers to clear the subsidy and support in generating a critical mass of turnover is a potentially valuable role for the private sector.

Another key factor currently constraining the uptake of groundwater irrigation is the lack of sufficiently detailed and accurate data and maps regarding soil, hydrogeology and water resources. iDE Ethiopia has reported about 80% success rate in manual well drilling, but it is viable only in specific hydrogeological settings (Weight et al., 2013). Interventions in mapping, data collection, drilling and test of wells are needed to effectively target high potential areas. Database containing such information could also be used to assess the potential and monitor impacts of a variety of investments in water access, utilization and agricultural water management.

2.1. 4. Cost-benefit Analysis of Groundwater Irrigation

Complementing the above study, the project team also examined the viability of groundwater irrigation investments in the Raya-Kobo Valley (Gebregziabher et al., 2013b). With few exceptions, the empirical results show that investment in groundwater irrigation is viable. Although institutionalization of cost sharing has challenges and carries associated transaction costs, the study recommended a cost-sharing plan to improve the sustainability of investment in groundwater irrigation.

Institutionalizing cost sharing effectively requires: (1) improving on-farm production efficiency, which presents opportunities for increasing income and hence farmers' capacity to share part of the initial investment costs; (2) strengthening the capacity of Water User Associations (WUAs) to manage and maintain the systems and foster active participation of farmers in promoting irrigation and the cost-sharing scheme; and (3) expanding rural electrification, which would benefit the rural community as a whole. Addressing these issues through integrated and full participation of users would capitalize on the willingness of farmers to adopt new approaches that may lead to increased yields and sustained incomes.

2.1.5. National Mapping of Agricultural Water Management

The Agwater Solutions Project also mapped the potential for AWM to improve the livelihoods of smallholder farmers in Ethiopia and found that just over 38 million people (56% of the rural population) could benefit from AWM (Evans (eds.), 2012; FAO, 2012). That study showed a range of AWM options that already exist in different parts of the country that can support the realization of this estimated potential, including river and stream diversions, rainwater harvesting, and soil and water conservation. The Government of Ethiopia has made a commitment to increase irrigation, and there are many opportunities for further investment to overcome the key constraints, including those identified above. Examples from the study are listed below:

- Water-lifting technologies could benefit between 1 and 2 million farm households.
- Groundwater and manual well drilling could be greatly expanded with investments in hydrogeological maps and groundwater data; and financing for private sector drilling and building a pool of skilled labor for the drilling industry.
- Land rehabilitation, water availability for supplementary or full-scale irrigation, and new agronomic practices are already improving land and crop productivity and increasing cultivated area in the country's watersheds. Additional investment in community-based watershed management could significantly help the government achieve its aim of making agriculture the driving force of economic development in Ethiopia.

2.2. Lessons from other IWMI-led projects

Apart from the AgWater solutions project, IWMI has implemented a wide-range of projects supported by various development partners that are producing information and innovations directly relevant for improving irrigation policies and practices (and more broadly Agricultural Water Management (AWM)) in sub-Saharan Africa (SSA) in general and Ethiopia in particular. Some of the projects that have contributed to this lesson learning include:

2.2.1. Improving Irrigation Performance in Africa

(French acronym: APPIA; Supported by the Government of France)

This project produced and field-tested in Ethiopia and Kenya a participatory diagnostic tool that farmers and technicians can use to identify gaps in irrigation scheme performance and develop implementable solutions.

2.2.2. Multiple Use Water Services (MUS) Project

(Supported by the CGIAR Challenge Program on Water and Food-CPWF)

MUS Project documented the outcomes, benefits and costs, and implementation strategies of MUS as opposed to single-purpose water supply schemes, using a “learning process” as a means for participants to learn together. That approach has also been recommended and promoted by donors.

2.2.3. Irrigation and poverty impact in Ethiopia

(Supported by the Government of Austria)

This project documented irrigation development and future potential, and analyzed the performance of irrigation, with a special focus on the impacts of irrigation investments on poverty reduction, food security and income in Ethiopia. It has provided tools, methods and guidelines for assessing, testing and refining irrigation impacts, which can be used by implementing agencies in Ethiopia, as well as other countries.

2.2.4. Rethinking Water Storage for Climate Change Adaptation in Sub¬-Saharan Africa

(Supported by the Government of Germany)

An assessment was made of a variety of options for water storage for AWM as a way of adapting to the impacts of climate change. The research results can be used to understand and develop irrigation commodity value chains, specially looking at inputs and production.

2.2.5. Groundwater in sub-Saharan Africa: Implications for food security and livelihoods

(Supported by the Alliance for a Green Revolution in Africa and the Rockefeller Foundation)

This groundwater research sought to identify the potential and opportunities for exploiting groundwater for AWM in sub-Saharan Africa. This would provide lessons for harnessing the untapped groundwater resources in Ethiopia.

2.3.6. Agricultural Water Management Technologies in Ethiopia

(Supported by USAID)

The project brought together researchers, policy makers and implementers of AWM in Ethiopia to share lessons learned. It also carried out an inventory of AWM practices in Ethiopia and assessed the poverty impacts of these technologies and practices.

2.2.7. Nile Basin Development Challenge: Improving rural livelihoods and their resilience through a landscape approach to rainwater management in the Ethiopian Highland

(Funded by the CPWF)

The focus of this research was on improved rain-water management practices toward improving the livelihood and income of farmers, improving productivity and ecosystem functions of the land and water resources and reversing environmental degradation.

All projects mentioned above have provided lessons that will strengthen the implementation of the USAID-ILSSI project. Examples of key lessons learned include:

- Provision of even relatively small amounts of water at key times can make an important contribution to peoples' well-being and livelihoods. Irrigation and access to agricultural water management technologies can significantly reduce poverty.
- Direct and indirect benefits of irrigation (i.e. increased crop productivity, employment, wages, increased food supplies/food security/food affordability etc.) vary greatly across settings.
- Impacts of irrigation investments, whether in new development or in the improvement of existing systems are situation specific. For example, depending on the circumstances investments in irrigation can be strongly pro-poor, neutral or even anti-poor.
- Equity and security in access and rights to resources matter for larger poverty impacts.
- The poor performance of many small-scale irrigation schemes is related to flawed project design and lack of adequate community consultation during project planning and implementation.
- Implementation of individual water management technologies is successful if implemented in an integrated manner.
- Past investments in irrigation and water harvesting have rarely integrated livestock management and crop production options and have often failed to maximize benefits and sustainability.
- Poor people need and use water for a wide range of essential activities. Deliberately making provision for these multiple uses of water when designing and managing water

supply and irrigation schemes can greatly reduce poverty, increase gender equity and improve health at low cost.

- Communities can improve their livelihoods and natural resources significantly despite having degraded biophysical and socio-economic conditions around them. However, to achieve this, drivers are needed in the form of strong individuals, new community organizations, innovative technologies and practices and/or external agents.
- Rainfall variability is a major impediment to the livelihoods of many poor people that will most likely get worse as a result of climate change. Under such circumstances water storage, in a variety of forms, is a key intervention, but in any given location it must be fit for purpose.

2.3. Lessons from ILRI-led projects

2.3.1. The Africa Research in Sustainable Intensification for the Next Generation or Africa RISING

(Supported by USAID)

AfricaRising aims to create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base. The project aims to identify and validate solutions to problems experienced by smallholder crop-livestock farmers in the Ethiopian highlands. Since some of the implementation sites of Africa RISING may overlap with the USAID-ILSSI project, it will create strong synergy and learning alliances.

2.3.2. Livestock and Irrigated Value-Chains for Ethiopian Smallholders, also known as LIVES

(Supported by Canadian International Development Agency-CIDA)

LIVES aims to contribute to enhanced income and gender equitable wealth creation for smallholders and other value chain actors through increased and sustained market off-take of high-value livestock and irrigated crop commodities. Since the objectives of LIVES are very much in line with the objectives of USAID-ILSSI project, there is opportunity for strong synergy and cross-project learning.

2.3.3. Improving the Productivity and Market Success of Ethiopian Farmers (IPMS) project

(Funded by CIDA)

The predecessor of LIVES project, some of the key lessons that can be learned from IPMS include: the importance of involving a wide range of stakeholders from the start of the development and implementation of a projects; the joint identification of the core problems; utilizing innovation systems that integrate expert and research expertise with local and indigenous knowledge; the importance of prevailing regulatory and policy environments; and development of solutions from the available technical, socio-economic, institutional and policy options. Lessons learned from IPMS will be valuable for the success of the USAID-ILSSI project, particularly enhancing the income and wealth creation of smallholder farm households.

3. Proposed interventions

3.1. Technologies for improved agricultural water management

Feed the Future (FtF) Innovation Lab on Small Scale Irrigation (USAID-ILSSI) in Ethiopia, Tanzania and Ghana is planned in such a way to identify, test, demonstrate technologies and put evidence forward for dialogue among the stakeholder community and policy makers. The project will focus on representative sites which will be defined later using targeting-framework. As a guide for the stakeholder discussion we proposed the following interventions.

a. ***Pilot Water lifting irrigation technologies.*** The purpose of this intervention would be to review and identify suitable water sources/storage, delivery, application of irrigation water and management systems where smallholder water lifting irrigation technologies suit better without jeopardizing the environment. Although conflict over groundwater use is not presently high, this is likely to rise when pressure on groundwater increases. Trends show that smallholder irrigation technologies usually spread spontaneously and unregulated. Hence, small but dispersed water extraction points may pose sustainability risks of resource depletion leading to conflict between users. As part of a smallholder water lifting irrigation technologies pilot, therefore, we will: i) study optimum depth of well as appropriate to a specific water lifting device, ii) contribute understanding of groundwater recharging zones and strategies to protect them, iii) determine well spacing; and iv) understand types of water lifting technology that suit a specific source of water. These would be follow up-activities to the AgWater Solutions project.

b. ***Assess gender disaggregated constraints to adoption of smallholder irrigation technologies.*** Better understanding of the constraints and challenges enables generation of possible practical solutions in terms of start-up capital and taxes that are of benefit the poor. Such a study could include exploring credit arrangements to enable farmers to purchase water lifting technologies and exploring opportunities for pump rental markets and private sector support to produce irrigation equipment locally to benefit the smallholder.

c. ***Assess institutions to improve access to market information*****.** Information asymmetry on input and output markets is a limiting factor. The market is thin and buyers act monopolistically to determine prices. Hence, we will assess institutions toward improving access to market information and linkages between smallholder producers and private businesses, traders, out- growers, universities, etc.

d. ***Demonstrate in-situ rainwater harvesting and soil fertility management technologies***. This will include three broad areas: soil, water and plant nutrient management. Less water in the soil could lead to water stress, while less fertilization leads to nutrient stress and thus poor water uptake and low water productivity. One identified constraint is soil crusting and compaction, which decreases rainwater infiltration and increases surface runoff. Toward overcoming such multifaceted problems, pilot interventions would examine deep tillage to improving soil moisture holding capacity, increase infiltration and reduce surface runoff. These also permit plant roots to exploit water and nutrients at deep horizons. Potential rainwater harvesting and soil fertility management technologies could include: i) check dams and deep trenches to enhance ground and surface water recharge; ii) deep tillage to increase soil water holding capacity; iii) effective use of stored water using water saving technologies; iv) surface residue mulching and cover cropping to minimize evaporation; v) application of fertilizer and organic manure to increase crop-water use efficiency.

e. ***Evaluate impact, constraints, opportunities and feasibility (cost-benefits) of technologies and interventions*** through household and community level surveys and modelling.

3.2. Framework and technologies to integrate fodder into small-scale irrigation

Despite the important role of the livestock business in the smallholder livelihood, most parts of Ethiopia suffer from: shortage, spatial and temporal variability of feed quantities and quality. This contributes not only to its current low performances but also failure to target Ethiopian holiday markets (Haileslassie et al., 2011). Implementing small-scale irrigation management and technologies combined with integrating fodder into small-scale irrigation could guarantee two to three crops per year and a year-round supply of green fodder leading to more productive crop-livestock systems. The general understanding is that integrating fodder into small scale irrigation will: i) help to synchronize availability of high quality fodder with potential livestock market; ii) be a model for feed resources based small-scale business which can link the land owner and landless farmers, iii) create a base for wider adoption of livestock business (e.g. fattening and dairy); and iv) where suitable irrigation technologies and high quality management is used to integrate farming technologies and animal feed with food crop production on irrigated farms, it should be possible to exploit complementarities and thus improve the efficiency and overall productivity of irrigation water resources. In fact, participants of an online survey were asked how likely was an introduction of fodder into small scale irrigation to improve the livelihood of small holder farmers: 53% replied very likely and 23% replied extremely likely. The on-line survey also examined success factors. To get stakeholders' opinions on success factors for integration of fodder into small-scale irrigation, >75% of the respondents stated that they believe that land size and quality are important factors. Other factors such as market, access to productive animals, volume and quality of water supply, type of water delivery and dominant production system were mentioned as important. In order to tackle the most important constraints limiting integration, we propose a possible framework to integrate fodder into small scale irrigation (Figure 1). On the left, the framework illustrates success factors to integrate fodder production into small- scale irrigation, and on the right side, it shows possible technologies pertinent to spatial-temporal dimensions as a basis for further discussion.

3.2.1. Framework to integrate fodder into small-scale irrigation

Land size is one of the major limiting or enhancing factors. As landholding declines, per capita food production and farm income also decline, an indicator that extremely smallsized farms have less capacity to invest in external inputs such as irrigation. On the other hand, land fragmentation makes land water linkages more difficult compared to a consolidated plot. For example, a farm household with three plots located at different places may need three water sources, which has strong implications on the magnitude of investment. Above all, the key priority of a smallholder farmer is short-term and food self-sufficiency; thus they opt more for irrigated crop than fodder.

It is not only the size of the land that matters, but also its location in relation to available water sources for irrigation. Despite huge water resources, most smallholder farmers suffer from inaccessibility of their plots to sufficient quantities of water. This in most cases leads to crop failure or under productivity in general. In light of high rainfall in Ethiopia and several big rivers, the problem is economical rather than physical water scarcity. Economic water scarcity is a type of water scarcity caused by a lack of investment in water or insufficient human capacity to satisfy the demand for water in areas where the population does not have the necessary monetary means to utilise an adequate source of water. Symptoms of economic water scarcity include a lack of infrastructure, with people often having to fetch water from rivers or lakes for domestic and agricultural uses. Large parts of Africa suffer from economic water scarcity; developing water infrastructure could therefore help to reduce poverty. Generally important, a proportion of water in highland areas of Ethiopia is lost as runoff. Capturing this and channeling it to where and when it is most needed is a function of cost and also policy decisions.

In light of the high investment required for water delivery, adoption of small scale irrigation farmers requires access to reliable markets. Beyond its limitation on adoption of small-scale irrigation, access to markets also influences farmers' decisions on crop selection, and also, therefore the model of integration of fodder into their irrigated farms. For example, high demand for onion during the Easter holiday period in Ethiopia usually pushes farmer to grow onions. As onions can grow in partial shade, this is an opportunity for spatial integration of fodder crops through intercropping.

The dominant production system also influences the type of fodder integration model a farm can adopt. For example, a year-round feed supply is an issue for intensive dairy farm systems. When there is such demand, farmers will benefit both from the sale of green fodder and also from animal products by adding value. Similarly, this is also a feasible option in pastoral areas as land has no other opportunity costs and farmers have slim alternative opportunities for livelihoods.

Equally important are the productivity levels of livestock, the purpose of animal husbandry, the breed and the herd structure. Recent study by Ayele (2012) suggested that the major purpose of livestock holding in the Ethiopian Nile basin (Ethiopian highland) is mainly animal power. Normal, effective working days for draught animals is about 120 days, which normally overlaps with the rainy season. As such, investment in irrigated fodder has not been a priority. In contrast, for productive dairy-based systems and fattening of small or large ruminants, farmers may adopt technologies of irrigated fodder much easier. This implies also that changing the mind-set of smallholder farmers into business-oriented livestock management will be a 'game changer' for integration of fodder into irrigation practices. This needs evidence, demonstration and dialogue, and also market linkages.

In summary, determinants for integration of fodder into irrigation practice are interdependent and interactive. For a successful adoption of irrigated fodder, farmers need sufficient land, water and productive animals, and proper input and output market linkages.

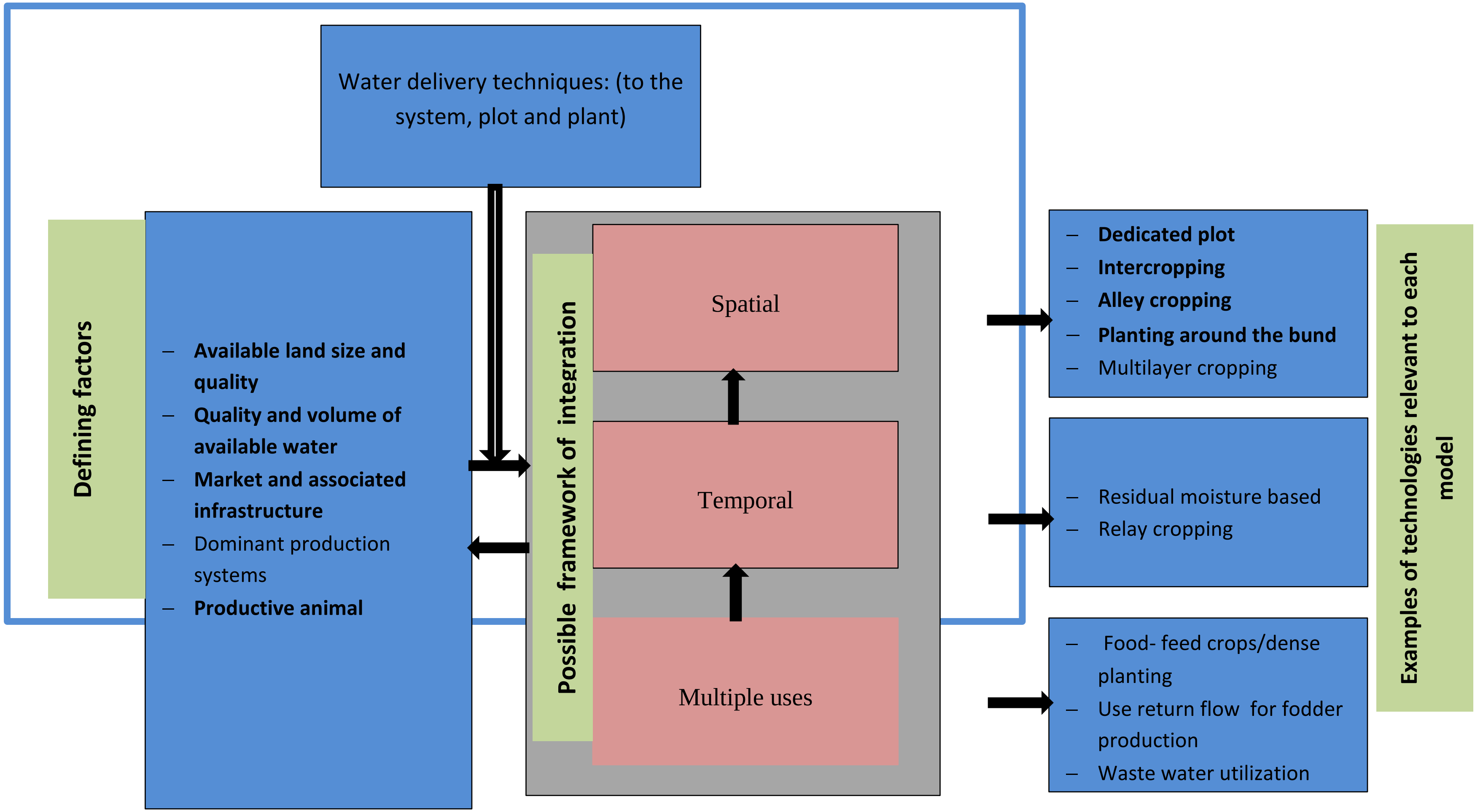

Figure 1: Simplified conceptual model to integrating irrigated fodder into small scale irrigation

3.2.2. Examples of technologies

Dedicated fodder plots

Dedicating plots of land to irrigated fodder is an example of spatial integration. This practice is feasible mainly in areas where there is sufficient land and water. A simple online survey suggests that this technology is not common in Ethiopia. Generally, even where farms are small, farmers may allocate a small portion of their plot to irrigated fodder where market linkages are good. The decisive factor in the farmer's eye is the opportunity cost of land and risks related to market failure. Therefore, by targeting action sites with good access to market and availability of productive animals, the option of dedicated fodder plots should be explored. It may work very well in areas where pastoralism dominates, large areas are available, water is not a limiting factor (e.g. where there is large river diversion) and opportunity costs of land and water is lower. One major advantage of this option is that fodder variety selection is not limited by the type of major crops farmers are planting. Very high yielding and space demanding species such as Napier grass (Pennisetum purpureum), alfalfa (Medicago sativa L.), and sorghum [Sorghum bicolor (L.) Moench] can be targeted. Under this option, multiple-cut perennial fodder varieties can be considered.

Inter-cropping

Where land is scarcer intercropping is one way of spatially integrating fodder into small-scale irrigation. Despite the possible trade-offs on biomass yield, intercropping is a good candidate for areas where land is short. From the online survey about 15% of the respondents mentioned their experiences in Ethiopia. Depending on the local conditions, intercropping can be in the form of strip, row, mixed and relay intercropping. The decision on the kind of intercropping of fodder (strip, row, mixed and relay) with the main crop depends on the type of crops farmers are targeting for food. As it depends on context, the most suitable fodder can be selected through on-farm exploratory and diagnostic trials. Generally for selection of fodder and crop species for intercropping the following criteria must be met:

1. As much as possible, the technology should not compete with or displace food/cash crop unless the monetary value is on par with the opportunity cost of the land.
2. The intercrop must be shade tolerant and extract its nutrients and water from a different layer of soil than the major crop (different root zone).

3. The fodder crop must be high yielding and sufficiently nutritious to be used as supplementary feed to basal feeds based on crop residue and native hay.
4. It must be responsive to intensive management such as fertilizing/manure application and irrigation, and must be tolerant to frequent clipping.

Combinations of cereals such as maize (Zea mays L.) and fodder legumes like cowpea (Vigna unguiculata) can be a useful form of intercropping. Intercropping onion (Allium cepa) and maize on irrigated rain-fed fields is also common in dry-land parts of India. The deeper rooting systems of maize and the shallow-rooted onion are a good combination to exploit moisture and soil nutrients in different soil horizons. Maize is a cereal and has high nutrient requirements and cow pea is a nitrogen-fixing legume that can supply nutrients leading to potentially synergetic effects. Although there are existing experiences and research outputs on the effects of spacing and crop combinations on yield, further farm exploratory and diagnostic trials are warranted. It could work to intercrop combinations of perennial crops (e.g. Babana, Musa acuminate) and annual forage legumes such as vetch (Vicia sativa ssp) and cowpea(Vigna unguiculata (L.) Walp.). As previously shown, the effect of seeding density and other agronomic parameters on yield are site specific and dependent particularly on the soil and climate. Thus, on farm trials are important to identify context-specific optimal practices.

Use of bunds

Construction of bunds around field boundaries is common for smallholder plots. Usually bunds are used to separate neighbouring fields. A bund is usually infested by weeds and can be a major source of weed seed. Therefore, planting fodder on bunds is useful both for weed control and for provision of livestock feed. This practice can be also applied to riparian buffers which are strips of permanent vegetation located along or near active watercourses or in ditches where water runoff concentrates. It is suitable for farmers who face land and water constraints. The opportunity costs of land are minimal and plants growing on bunds may not need additional water for irrigation as the fodder plants can use the subsurface flowing water from irrigated fields. Planting on bunds can create a good wind barrier reducing evaporative water losses from the soil surface. A result from online survey suggests that this is the most frequently observed practice in Ethiopia (>75% of the respondent). The challenge is that such practices require agreement among adjacent farms to avoid potential conflict. Technologies such as tree lucerne (Chemacytisus palmensis) are also a very good option. It may need irrigation for establishment and then it uses more soil moisture. Also, perennial grasses such as Napier grass (Pennisetum purpurem) and multipurpose trees such as Leucaena leucocephala, Leucaena pallida and Sesbania sesban may work very well for on-farm boundary or soil and water conservation bunds.

Under-storey planting

Significant proportions of small-scale irrigators in Ethiopia grow perennial crops (personal communication, LIVES project). These include banana, citrus and papaya. These are usually structurally tall crops and there is space in the under-storey which could be potentially used for other crops. Multi-storey cropping is a common technique under such circumstances. Legume fodder plants that occupy the lower spatial horizons can fit here (e.g. varieties of groundnuts, cowpea). This technique not only helps for improved uses of land and water, but also to exploit solar energy by carefully planning the vertical arrangement of the different plants. Nitrogen fixation by fodder plants is another major benefit that can be reaped from multi-storey cropping. Despite these potentials benefits under-storey planting technologies did not emerge among the currently observed practices in Ethiopia.

Relay cropping

Relay cropping is a common agronomic practice to integrate different crops and maximise use of scarce land. With very careful selection of crops, integration of fodder into irrigated farming can take the form of relay cropping. In relay cropping, at planting time two or more crops of different harvest durations are cultivated in the same field. Once the main shorter duration crop is harvested fodder crops have more space to grow. A good example is relaying of sorghum and onion in India (Bijapur district, Karnataka, personal field observation). This innovative model of relay cropping has not only achieved the scientific objective of better crop management, but also gives higher returns to farmers through advantages in space and time allocation. It also reduces loss of soil moisture from bare soil and thus converts evaporative losses to beneficial outputs, which ultimately improve the water productivity of the system. Relay cropping also reduces risk of uncertainty, enhances utilization of natural capital (land, water) and optimizes use of external resources (fertilizer, pesticide). This practice reduces the cost of cultivation per unit overall yield and increases net returns (including irrigation returns) from a given piece of land.

With increasing land and water shortages across developing countries, there are strong arguments that the agricultural system must intensify and focus more on food-feed crops so that the interaction of system elements such as crops and livestock will be complementary and resource-use efficiency enhanced. Integrating food-feed crops such as irrigated maize can be an important avenue for improved efficiencies in use of increasingly scarce land and water. Particularly, the use of maize for green corn allows early harvesting of the green maize stover which can be used as animal feed. Silage techniques can be explored for improved feed quality and storage. Green maize also has a shorter growing period compared with harvesting at physiological maturity allowing for planting of fast-growing relay crops (e.g. vetch) using residual moisture. A combination of maize and lablab (Lablab purpureus) is also possible.

One of the major hurdles for adoption of planted fodder in Ethiopia is lack of access to planting material. In addition to the above proposed intervention, the ILSSI project could pilot community nurseries as a major source of seedling and also form a focus for capacity building and community dialogue.

4. Summary of high potential interventions for discussion

This paper is intended to provide the basis for consultation with stakeholders comprised of Government of Ethiopia officials, scientists, researchers, practitioners and implementers. Based on previous and on-going projects, as well as the results of previous research and lessons learned, this paper proposes a number of promising interventions in AWM, irrigation and integrated fodder production, which are listed below:

1. **Piloting of a combination of water lifting irrigation technologies with various water sources**
2. **Demonstrate irrigated fodder integrated into small-scale irrigation, including: dedicated fodder plots, intercropping, use of bunds, and relay cropping**
3. **Demonstrate in-situ rainwater harvesting, ground and surface water recharging, and soil fertility management technologies, including deep tillage**
4. **Analysis of gender and institutional constraints and opportunities for potential interventions**

The project seeks to have continued dialogue and collaboration throughout the proposed research in both the field-level piloting of interventions and the modelling of the potential economic and biophysical opportunities, constraints and sustainability.

Annex 1: Characteristics of Smallholder Water Lifting Irrigation Technologies

Technology	Source of water	Storage	Conveyance	Application	Use/Production	Drawbacks/Limitations of technologies
Motor pump	Ground Surface	Shallow/hand-dug well Pond River Dam/reservoir	Hose Unlined/soil ditch canal Lined canal	Farrow irrigation Drip/sprinkler	Vegetables Cereals/staples Fodder	High cost of investment and lack of adequate financing mechanisms high operation and maintenance cost Frequent break down Lack of maintenance and spare part supply services Weak supply chain Creates income gap between male and women, and poor and wealthier farmers Unregulated and spontaneously dispersed extraction points leading to water resource depletion High and rising fuel price.
Treadle pump	Ground water Surface	Shallow well Hand-dug well Rivers Canal Pond Dam/reservoir	Unlined canal	Farrow	Kitchen garden Vegetable Fodder	Pumping depth very shallow Low pumping capacity Low quality products. Dis-adoption: Treadle pumps have significantly diminished in importance Drudgery/labor intensive Irrigate small plots
Rope & Washer	Groundwater	Tube well	Canal Bucket Hose	Furrow Labor l	Backyard irrigation Vegetables Fodder	Pump is open to the air and contamination of the rope With deep wells, it takes some time before the Rope pump delivers water. Not suitable for communal use Irrigate small plots
Solar pump	• Groundwater	Tube well	Canal Bucket	Furrow Labor	Backyard irrigation	High investment cost, Water storage required for cloudy periods

			Hose		Vegetables Fodder	Repair require skilled technicians Doubting to reach more number of beneficiaries Large areas required to capture the suns energy
Bucket	Ground Surface	Shallow/hand-dug well Pond River Dam/reservoir	Labor	Labor	Backyard/kitchen garden Fodder	Not appropriate to irrigate large size of land Labor intensive/drudgery

Annex 2: Proposed interventions and Activities

Proposed intervention	Proposed activities/Inputs to increase impact of SSI
Piloting of water lifting irrigation technologies	**i)** Review and identify suitable Water sources/storage, conveyance/delivery, application and management systems where smallholder irrigation technologies suit better, **ii)** Study and determine optimum depth of well as appropriate to a specific water lifting device, **iii)** Study groundwater recharging zones and well spacing and type of water lifting technology that suit to a specific source of water, **iv)** Develop a registry of motor pump importers, dealers, retailers and after-sales service providers, **v)** Assess the type and quality of irrigation technologies in the market and identify the major bottlenecks to improve the supply chain and procurement system of motor pumps, **vi)** Engage and support irrigation technology dealers in setting up demonstration plots to strengthening extension services, **vii)** Assess gender disaggregated constraints to adopt irrigation technologies, and explore credit/financing mechanisms to adopt water lifting technologies, **viii)** Assess and support institutions in improving access to market information, **ix)** Study why some farmers dis-adopt some of the technologies they used before.
Demonstrate irrigated fodder (integrate fodder in small-scale irrigation)	**i)** Development of fodder-irrigation integration framework. Community consultation to identify opportunities and gaps to produce irrigated fodder, **ii)** Assess input and knowledge constraints to produce irrigated fodder, **iii)** Assess market opportunities for irrigated fodder (both for green fodder and animal products), **iv**) Identify model farmers who integrate crop and fodder and use them for demonstration,
Demonstrate ground/surface water recharging, in-situ rainwater harvesting and soil fertility management technologies.	Demonstrate integrated technologies for improved soil, water and nutrient management, such as: **i)** check dam and deep trenches for rainwater harvesting, reduced erosion and increased ground water recharge; b) hard pan braking for improved water infiltration and reduced surface sealing of soils to permit plant roots to exploit water and nutrients at deep horizons; **ii)** Demonstrate on shelf hard pan breaking technologies (for example, 'tenkara Kind by Giz' and 'All-In-One hand driven two-wheel tractor' developed by engineer Solomon of Mekelle University); **iii)** fertilizer and organic manure application to increase crop-water use efficiency; **iv)** Use and demonstrate water saving technologies for efficient use of stored water; **v)** Use and demonstrate surface residue mulching and cover cropping to reduce evaporation
Conduct household and community level survey	**i)** Implementation of household survey for intervention areas to evaluate impact analyses and compare cost-benefits, constraint (gaps) and opportunities, of smallholder irrigation technologies and interventions. **ii)** contribute in the development of data acquisition and consolidation plan to overcome shortfalls in relevant data needed by GDSS, **iii)** Review candidate interventions from previous and on-going projects for use of SSI in food and forage production, **iv)** Contribute to the development of tools for focus group discussions with farmers, project managers and government officials, **v)** Develop targeting and monitoring framework for assessing likelihood of success of intensive irrigated vegetable and forage production in specific locations, **vi)**

	Assess availability of land, labor, water for crop and fodder production and market for products, **vii)** Monitor field tests for identified technologies and practices, **viii)** Collect qualitative and quantitative data required for analysis of gender related constraints, institutional bottlenecks and ex-ante analysis.
Capacity Building/Development	**i)** Contribute to the development of comprehensive training plan, **ii)** Contribute to the establishment of GDSS user group including CGIAR and national partner users, **iii)** Participate and contribute in trainings for farmers and local stakeholders (extension, Bureau of Agriculture) for each field site area, **iv)** Contribute and participate in post-doctoral research training, **v)** contribute in review/revise of stakeholder maps, **vi)** Contribute in the development of engagement plan for individual interventions at different levels, **vii)** Stakeholder consultation to make sure interventions are demand driven and aligned with national plans and programs.

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