WATER PRODUCTIVE AND RESILIENT LANDSCAPE MANAGEMENT TECHNOLOGIES AND APPROACHES Training Manual

Book · June 2020

3 authors:

Amare Haileslassie
International Water Management Institute
160 PUBLICATIONS 1,761 CITATIONS

Wolde Mekuria
Consultative Group on International Agricultural Research
93 PUBLICATIONS 2,736 CITATIONS

Anna Tengberg
Lund University
65 PUBLICATIONS 2,257 CITATIONS

WATER PRODUCTIVE AND RESILIENT LANDSCAPE MANAGEMENT TECHNOLOGIES AND APPROACHES

– Training Manual

June 2020

Amare Haileslassie
International Water Management Institute (IWMI)
Nile Basin and East Africa Office,
Addis Ababa, Ethiopia
email: a.haileslassie@cgiar.org

Wolde Mekuria
International Water Management Institute (IWMI)
Nile Basin and East Africa Office,
Addis Ababa, Ethiopia
email: w.bori@cgiar.org

Anna Tengberg
Stockholm International Water Institute (SIWI)
email: anna.tengberg@siwi.org

Stockholm International Water Institute
Linnégatan 87A, Box 101 87
100 55 Stockholm
SWEDEN

International Water Management Institute

Table of Content

List of Tables

List of figures

ASEAN	Association of Southeast Asian Nations
ASP	Asia Soil Partnership
BP	Best Practices
CACILM	Central Asian Countries Initiative in Land Management
CBD	Convention on Biological Diversity
CBO	Community Based Organisation
CBP	Carbon Benefits Project
CBT	Carbon Benefit Tool
CCA	Climate Change Adaptation
CDE	Centre for Development and Environment at the University of Bern
CESRA	Centre of Excellence for Soil Research in Asia
CFH	Swiss Franc
CI	Conservation International
CIAT	Center for Tropical Agriculture
COP	Conference of the Parties
CRIC	Committee for the Review of Implementation of the UNCCD
CSIR	Council for Scientific and Industrial Research (South Africa)
DS-SLM	Decision Support for Sustainable Land Management
FAO	Food and Agricultural Organization of the United Nations
FREG	Farmer-Research Extension Group
GCF	Green Climate Fund
GEF	Global Environment Facility
GEFSEC	Global Environment Facility Secretariat
GIZ	Gesellschaft für Internationale Zusammenarbeit (German Development Cooperation)
HIMCAT	WOCAT for the Himalayan Region
ICARDA	Science for Resilient Livelihoods in Dry Areas
ICIMOD	International Centre for Integrated Mountain Development
IFAD	International Fund for Agricultural Development
IKI	International Climate Initiative
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ISRIC	World Soil Information
LAC	Latin America and the Caribbean
LADA	Land Degradation Assessment in Drylands
LDN	Land Degradation Neutrality
LLPA	Local Level Participatory Planning
MOU	Memorandum of Understanding
MSP	Medium-Sized Project
NARO	National Agricultural Research Organisation (Uganda)
NDVI	Normalized Difference Vegetation Index
NEPAD	New Partnership for Africa's Development
OH	Outcome Harvesting
PRAIS	Performance Review and Assessment of Implementation of Practices
QA	Questionnaire on SLM Approaches
QCCA	Questionnaire on Climate Change Adaptation
QM	Questionnaire on Mapping
QT	Questionnaire on SLM Technologies
RNE	Near East and North Africa
SDC	Swiss Agency for Development Cooperation
SDG	Sustainable Development Goal
SES	Social Ecological System
SLM	Sustainable Land Management
SPI	Science Policy Interface (Of the UNCCD)
SWC	Soil and Water Conservation
TE	Terminal Evaluation
TOR	Terms of Reference
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
WOCAT	World Overview of Conservation Approaches and Technologies

Introduction

Efficient use of water and building landscape resilience to system shocks, particularly to climate change, has become one of the priority areas for action. Climate change primarily disrupts the water cycle through evaporative losses (increased temperature), increased precipitation (flooding) and reduced precipitation (drought). Disruption in the water cycle in turn affects resilience of landscapes to stress both in terms of structure (e.g. land use change), ecosystem functions (productivity, biodiversity, supply of clean drinking water) and dynamics (change in time and space). This training manual presents 7 sets of modules and 15 associated sessions which could be delivered in three to five days. The content and scope of each of the modules varies depending on the practical usefulness to the trainees. The manual covers: 1) Definitions of terms and concept around resilient landscapes; 2) Approaches to resilient landscape and water management; 3) Sustainable landscape transformation - pathways development; 4) Water Efficient and Resilient Landscape Management Technologies; 5) Lifting, conveyance and on-farm water application; 6) Productive use of water; 7) Socio-economic considerations - with a focus on Irrigation Water User Associations (IWUAs). Many of the examples presented are from publicly available resources and the works of CGIAR centers (International Water Management Institute, International Livestock Research Institute, International Crop Research Institute for Arid and Semi-Arid Tropics and International Center for Agricultural Research in the Dry Areas. The manual covers both individual and group exercises and discussion points for analyzing problems and suggesting solutions. The different modules are presented as independent chapters, but links between different topics are discussed. The learning method will involve lectures, small group discussions, examples, and field work.

i. Objectives of the course material

The primary objectives of the manual are to elaborate the modules and associated sessions on technologies and approaches for water productive and resilient landscapes through examples supported by scientific findings. Secondly, it provides a reference material to the trainees which can be used as a practical guide during their day-to-day activities. The manual is a living document that can be used as a basis for exchange of opinions among trainees and non-trainees and thus indirectly contribute to wider technology and skill transfer.

ii. Why this course material

Achieving water productive and resilient landscapes requires a combination of measures, ranging from building capacities of practitioners, through planning to implementation and adaptive management. This manual focuses on building the capacities of practitioners for achieving water efficient and resilient landscapes. First, it will ensure that the trainees better understand the technical details of target technologies, and how and why they work. Second, it will enable the trainees to understand and match the technologies with the context and targeted landscape. Third, it will ensure the practicality of applying the innovation by using data from action research. Finally, matching the scope of the science to the needs of the audience and making the learning and teaching process more practical are important aspects.

iii. The process

This training manual was prepared using multiple steps. The initial idea came from observation and understanding of the lingering land and water degradation problems in Ethiopia. This makes the landscape and people increasingly vulnerable to climate change related system shocks. Observations were made at target sites (particularly the central rift valley system) and discussions were held with key stakeholders and a needs assessment was conducted. Following this, a course guide capturing the skills and capacity gap of the stakeholders was prepared. This course material is a combination of these process with: (a) examples of action research by the CGIAR centers and their partners, (b) national and global experiences on productive use of water and building landscape resilience, and (c) end-users or target audience consultation.

iv. Target Audience

The training is designed for the operational level and targets agricultural, soil and water conservation and irrigation experts, extension workers and development agents with a good understanding of landscape and agricultural water management.

v. The structure

The manual is organized into 7 chapters or modules and several sub-chapters. Given the complexity of several concepts around landscapes, resilience, agricultural systems, integrated systems and efficient water use, the manual starts with definitions and illustrations of these concepts using practical examples (Module 1). This is followed by Module 2 which exemplifies approaches to resilient landscape and water management. Here examples of conceptual and practical approaches, such as the agricultural system approach, the landscape approach, the rainfed and irrigation continuum and the value chain approach, are discussed. The third chapter (Module 3) is about sustainable landscape transformation and pathways development. This focuses on the dynamic (space and time) nature of landscapes and how we maintain and enhance sustainability in understanding, planning and implementing practices. The fourth chapter (Module 4) is about interventions and technologies for water-efficient and resilient landscape management. The examples of technologies here include in-situ and ex-situ water harvesting and thus have a direct connection with water lifting, conveyance and on-farm water application practices presented under chapter 5 (Module 5). For water efficient and resilient landscapes, the critical point is how scarce water resources could be used. In this regard, module 6 of the manual demonstrates the concepts and practices of productive use of water using examples of livestock and crop interactions which are the major consumers of freshwater resources globally. Instead of individual sectors (crop, livestock), the training will focus on complementarity between the two major sectors for efficient agricultural systems level water use. For all technologies to be sustainable, understanding water and landscape governance is critical (Module 7). Since this topic is too broad and complex to cover comprehensively, we focus on Irrigation Water User Associations in context of Ethiopia. The structure and flow of the modules is summarized in Figure 1.

vi. The training tools

The training is primely based on this manual and lectures and additional practical examples which could not be included here because of size limitation. Secondly, group work and discussions will be facilitated and guided based on critical thinking and discussion points presented in the manual. Thirdly, following group discussions/group work, short group presentations will be an important tool to cross-fertilize opinions and understanding between the trainees. The trainees will go out of their class during the first day to have a general overview of the surrounding landscape. More specific technical tools such as crop water requirement estimation tools; runoff estimation tools and; water productivity estimation tools will be demonstrated and used for various exercises. Stationeries such as flipchart and markers will be provided.

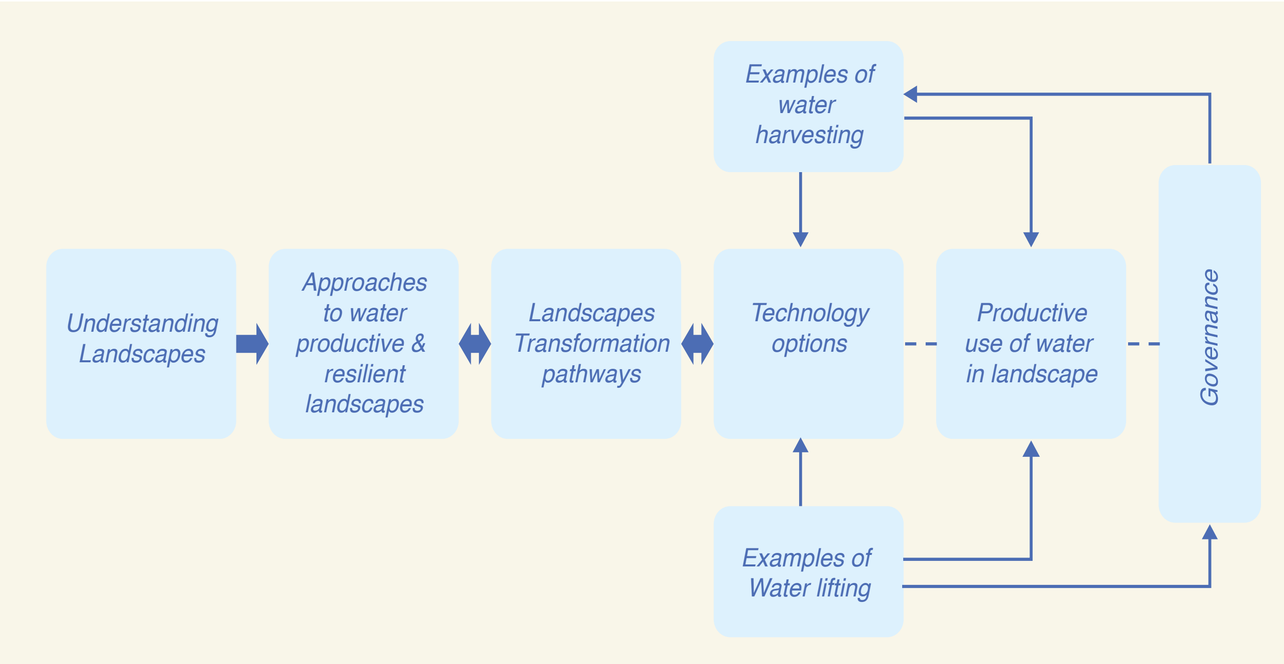


Figure 1: *Schematic flow and logical links of the training modules.*

Module 1: Definitions of terms and concept around resilient landscapes

1.1. Resilience

Resilience has been described and defined as (Walker et al., 2004; United Nations International Strategy for Disaster Reduction, 2005; Intergovernmental Panel on Climate Change, 2007):

1) The capacity of a system to absorb disturbance and reorganize while undergoing change'.
2) The capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing to reach and maintain an acceptable level of functioning and structure'.
3) 'The ability of a social ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change' (Figure 2).

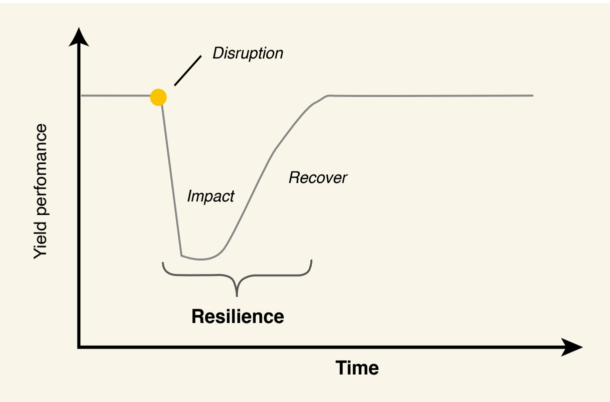


Figure 2 : *Illustration of the process and outcome of resilience.*

Resilience is thus an inherent property of a complex system and "landscape resilience" may not always be desirable (e.g. poverty trap), but desirable resilience helps landscapes adapt to change in the face of external drivers of change, such as climate change (Liao et al., 2020). A functioning hydrology in landscapes contributes to desirable resilience to external pressures and ensures provision of ecosystem services important for human well-being (Falkenmark, 2020).

Forests and trees have key functions in maintaining resilient and productive landscapes, communities, and ecosystems. They ensure water supply and provide high quality water resources through numerous physical mechanisms, e.g. interception of atmospheric moisture, contribution to cloud and rain formation, reduction of erosion and recharging of groundwater. In fact, around 75% of the world's accessible freshwater for agricultural, domestic, urban, industrial, and environmental uses depend on forests (Eberhardt et al., 2019).

Critical thinking and discussion points: system, absorb, disturbance, system structures, functions

1.2. Landscape

Despite the wealth of literature on landscapes and landscape approaches, the ideas of how to define and operationalise these concepts are diverse and vague (Freeman et al., 2015). One of the premises for taking a landscape approach is that integrated approaches are needed to address complex challenges related to sustainable development and so called "wicked problems" (Balint et al., 2011). Moreover, landscape approaches can be a mechanism around which civil society and other key users of the natural resources provided or produced in the landscape can discuss trade-offs and be mobilized to achieve better land use and water resource outcomes (Sayer et al., 2014).

Different approaches perceive agricultural landscape process, boundary, and scale differently. In ecological approaches, the main characteristics to define agricultural landscapes are spatiality, heterogeneity, and relationship between elements, including people or not. A unified landscape concept can be defined as a heterogeneous space portion where relationships between natural and cultural processes occur. A popular conception of landscape has been a portion of land or territory that the eye can catch in a glance, or area or scenery as seen by a human observer (Figure 3). Although this could be valid in drawing a boundary around specific agricultural landscapes, it misses some key attributes (structure and functionality) of landscapes. Alternatively, Karadağ (2003) proposes the use of a hydrological boundary [watershed or Hydrological Response Units (HRU)] as proxy to delineate the landscape boundary (Figure 4).

Generally, many watersheds or HRUs could be included in a landscape, and a landscape boundary may or not correspond to an HRU but the sum of HRUs in a landscape can provide an option to define the boundary of the landscape. Agricultural landscapes' structural components can also provide options for a boundary. Figure 4 illustrates watersheds nested in agricultural landscapes verifying the proposal of heterogeneous space portion where relationship between natural and cultural processes occurs.

Figure 3: *Partial view of Lake Hawassa catchment with human settlement, agricultural land and different agricultural practices (Photo credit: Amare Haileslassie).*

Figure 4: *Watersheds nested in an agricultural landscape*

A landscape can vary in size from a meter to tens of kilometers. The heterogeneity could be expressed as physically identifiable structures and could be a cluster of several farming/farm systems. For example, Figure 3 illustrates the different activities in different portions of a landscape (e.g. valley bottom farming, open grazing land in the upland). Landscapes do not exist in isolation and interactions occur with contiguous landscapes and within a landscape between system components (e.g. people and livestock). People move and water flows facilitating material fluxes (e.g. nutrient, products, energy (Granit et al., 2017; Haileslassie et al., 2005). Agricultural landscapes could also be conceptualized as layers of landscapes and systems. Smaller landscapes are nested in a larger one and so forth. In other words, each landscape has a context or regional setting, regardless of scale and how the landscape is defined. Because of space limitations and pressure from external factors, such as population growth and climate change, building resilient landscapes is increasingly important. There is a need to transform agricultural landscapes towards **multifunctional landscapes.** The strength of multifunctional landscapes is their ability to meet the needs of diverse uses and deliver multiple ecosystem services, including economic, environmental, and social.

Critical thinking and discussion points: layers of landscapes, systems in landscapes, HRU, multi-functional landscapes, open system/landscape

1.3. Water productive agricultural systems

When freshwater resources are scarce, improving water efficiency and productivity is advocated globally. The fact that agriculture (crop and livestock) consumes the largest proportion of freshwater resources, developing a water efficient and water productive agricultural system is important. The applications of concepts of irrigation efficiency (IE), water use efficiency (WUE) and water productivity (WP) are complicated. Efficiency and productivity are two different but interconnected indicators of performance of water uses.

Water use efficiency (WUE): Refers to the ratio of water used in the plant metabolism to water lost by the plant through transpiration. From an irrigation engineering perspective, efficient water use is defined as the ratio between the actual volume of water used for a specific purpose and the volume extracted or derived from a supply source for that same purpose. WUE is a dimensionless ratio of total amount of water used to the total amount of water applied.

Water Productivity (WP): The term WP plays a crucial role in modern agriculture which aims to increase yield production per unit of water used, both under rainfed and irrigated conditions. It refers to the ratio of biomass produced to the rate of transpiration. This can be achieved either by 1) increasing the marketable yield of the crops for each unit of water transpired, 2) reducing the outflows/losses, or 3) enhancing the effective use of rainfall, of the water stored in the soil, and of the marginal quality water. Evaluating water productivity efficiency for agricultural landscapes requires disaggregating the entire landscape to lower levels (e.g. farm, farm system, community, watershed). A water productive system is then the ratio sum of water input to the system (precipitation or irrigation) to the beneficial outputs delivered by system components [livestock products and services, crop production (Haileslassie et al., 2009)]. All these definitions or concepts indicate that in a water productive agricultural system, unproductive depletion (evaporative losses and pollution) is minimized and transpiration loss, which correlate with biomass yield, maximized. The principle in enhancement of system water productivity is to conserve and channel water to when and where it is most needed, enhance plant water uptake capacity and, conversion to beneficial outputs. The two (i.e. WUE and WP) are interconnected and increase of WUE would lead to better WP. Details are provided in later sections.

Critical thinking and discussion points: We propose a process for designing multifunctional landscapes, guided by ecological principles in the following steps:

- **Briefly go out of classes and see around for a typical landscape.**
- **Draw the landscape.**

Define landscape context and analyze landscape structures and functions - gaps in terms of multifunctional landscape.

Module 2: Approaches to resilient landscape and water management

As part of resilient landscape and water management approaches, this section discusses five selected approaches: 1) the agriculture/farming/livelihood system approach; 2) the integrated and optimization approach; 3) the value chain approach; 4) the irrigation-rainfed continuum and upstream-downstream interactions; and 5) the integration of trees in agricultural landscapes.

2.1. Agricultural/farming/ livelihood systems approach

In the context of Ethiopia and specifically in the rift valley system, there are several reasons to bring agriculture and livelihood considerations together. Agriculture is a major source of livelihood and user of freshwater resources. The agriculture/farming/livelihood system approach focuses on the understanding of the interactions between livelihood assets, agricultural activities and water resources management (Fig. 5). Each individual farm has its own specific characteristics, which arise from variations in resource endowments and family circumstances (Clement et al., 2011; Haileslassie et al., 2016,). The household, its resources, and the resource flows and interactions at individual farm level are together referred to as a farm system. It is the level of endowment of livelihood assets that determines efficient use of water and enhancement of productivity (e.g. Haileslassie et al., 2009a). As illustrated in Figure 6, the approach is characterizing and targeting interventions for farms, communities, and production systems that can build a resilient landscape (Haileslassie et al., 2009a)

Water is an interface between different system components and therefore efforts of intensification could be water centered. Tang et al. (2013) showed how livelihood assets, livelihood outcomes and vulnerability interact in the space of agricultural landscapes.

- Livelihood assets are interconnected and have synergetic effects.
- Livelihood strategies are about transformation between capitals, and enable both accumulation and transfer between capitals to meet livelihood outcomes and enhance adoption and resilience.

Considering linkages between different assets and existing structures and processes (policy, institutions) is important in building resilient landscapes

A farming system is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate (Haileslassie et al., 2009b; Haileslassie et al., 2012).

In order to analyze farming systems and their future development trajectories, key biophysical and socio-economic determinants could be grouped into three categories (Fig. 6):

1) natural resources and climate - green colored (also the system structure function is under this cluster),
2) pressure on the system including from science and technology (management system) and demographic forces system and change as a result (blue color), and
3) livelihood outcomes and feedbacks (Haileslassie et al., 2013a).

It is only through inclusion of these components in the system analysis that a comprehensive understanding of the system dynamics and its design of future trajectories are possible.

Critical thinking and discussion points:

- ✔ **Identify different livelihood assets and discuss how they influence the production process and landscape resilience to climate change shocks**
- ✔ **Discuss livelihood assets, capital transformation and improved wellbeing as a pathway to resilience of individuals, communities, systems, and agricultural landscapes**
- ✔ **Discuss examples of changing production systems and feedbacks**

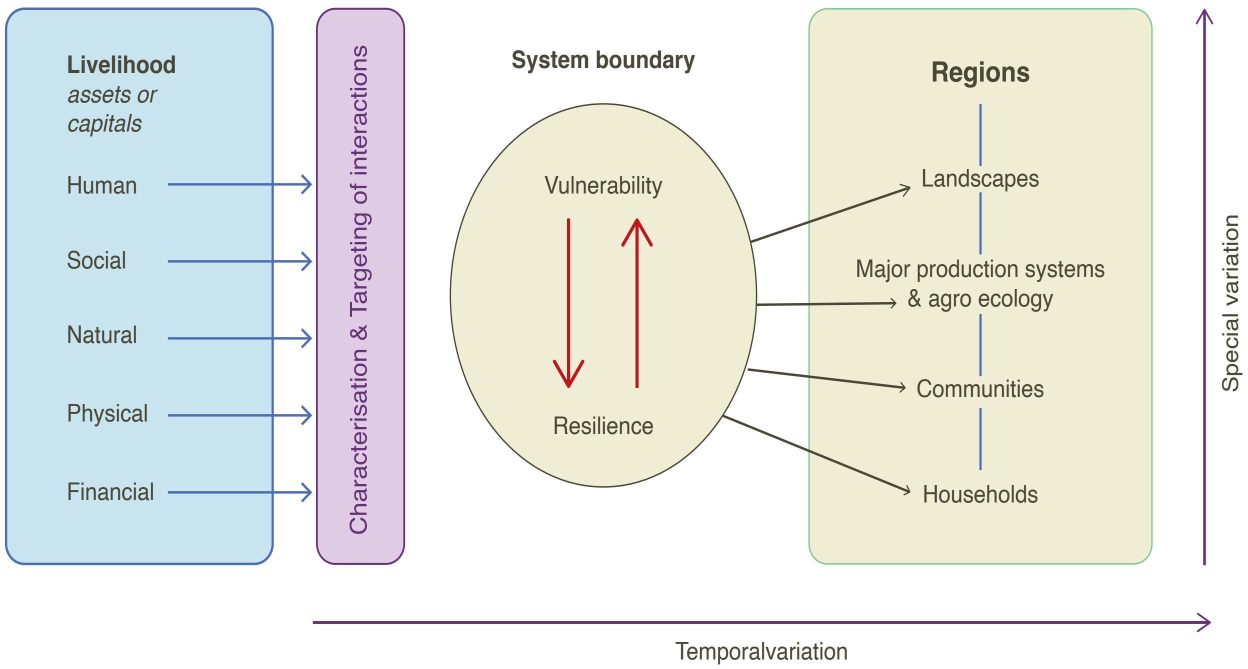


Figure 5: *Framework for production and livelihood system*

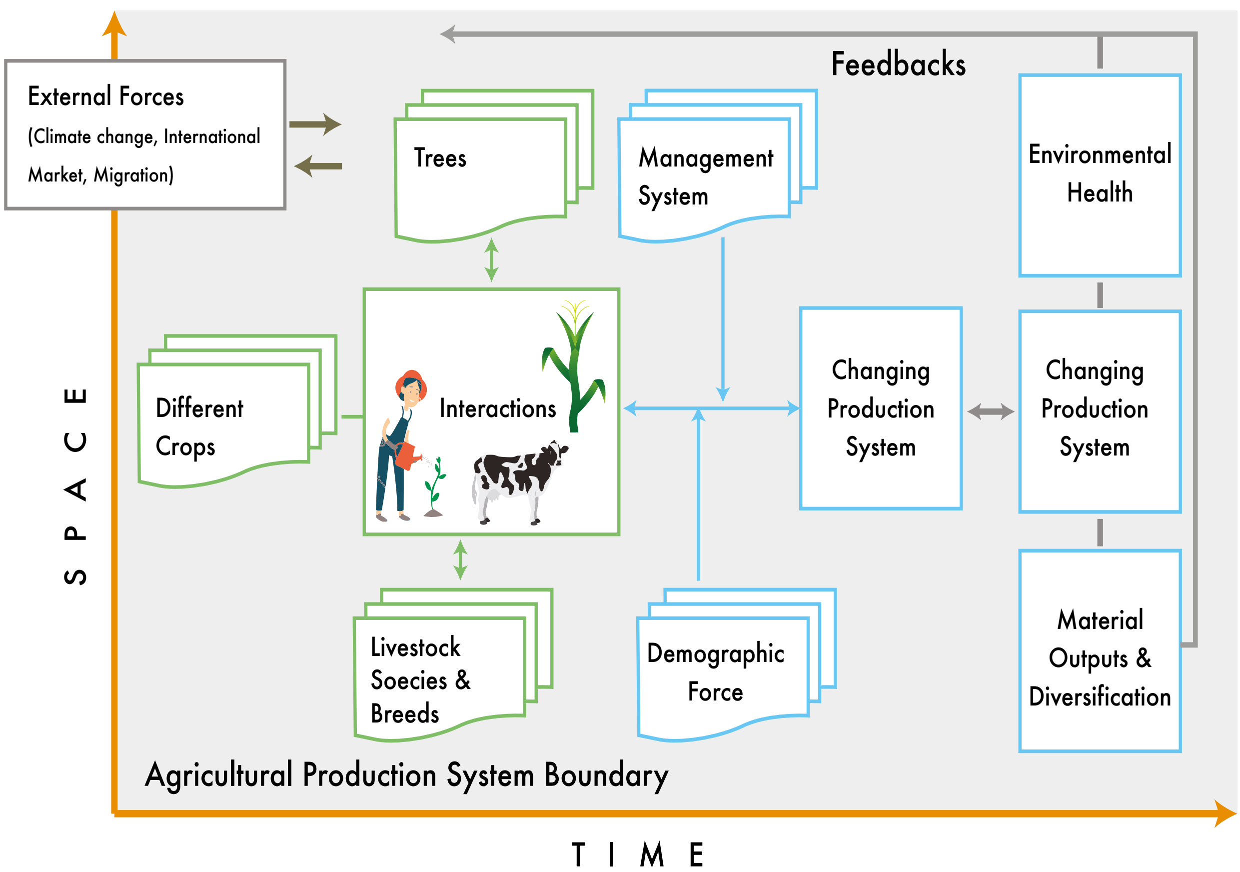


Figure 6 : *Framework for integrated agricultural system illustrating open system, structure, function, material flow and state and feedback loops*

2.2. Integrated and optimization approach

One of the major challenges in rift valley production systems (and landscapes) is the huge yield gap. The myth among farming communities is that more water application will increase yield and implicitly close the yield gap. However, closing the yield gap and improving the productivity of scarce water resources requires an integrated approach. For example, Smith et al. (2001) illustrated that with the same amount of water, farmers can produce more if they integrate different agricultural inputs (e.g., high yielding varieties, use of organic and inorganic fertilizers, Fig. 7). Water can be saved through better integration or use of different yield-limiting factors at a time. This means more water will be available for another use or expansion of production areas and thus livelihoods and landscapes will be resilient to climate change. For the same water input (e.g. at 5000 m3 ha-1), different levels of production can be obtained (Fig. 7). The challenge is identifying which combinations fit which environment. The economic and agronomic optimum level (Fig. 8), is an important tipping point. Further, improving the demand and supply side of water management and establishing longer-term data bases and improving surveillances of system dynamics is important.

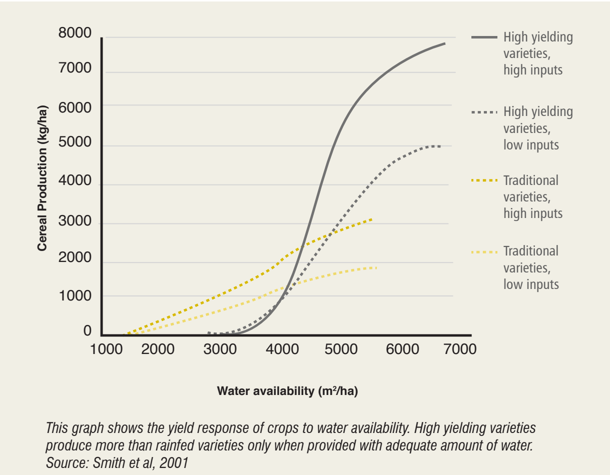


Figure 7: *Illustrating how integration of inputs save water and thus help in building resilient agricultural landscapes.*

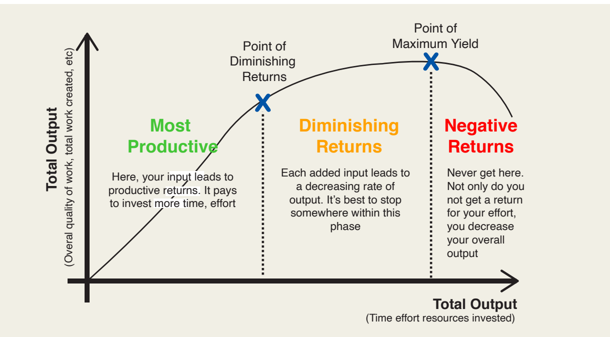


Figure 8: *Illustration of agronomic and economic optimum input rate for productive use of water.*

2.3. Value chains

The value chain concept has been around for some time. But adoption and application to agricultural water management (e.g. irrigation, rainfed system) is rarely observed in Ethiopia. Irrigation is capital, input and knowledge intensive. An example of timely supply of inputs of seed and fertilizers would enable integrated approaches and facilitate the production process. There are sequential and interconnected value-chain nodes ranging from input supply to consumption, and service provision is linked to each value chain node (Fig. 9). A value chain node, in its simple form, is a step across a value chain where clusters of activities are interconnected, and value created. For example, the irrigation sector needs closer service provisions (credit service, capacity building, swift maintenance of motor pumps or private sector involvement in water marketing). In summary:

- The value chain system comprises the value chain actors, service providers and the institutional environment in which the value chain operators and service providers operate.
- The institutional environment incudes formal and informal institutions, policies, laws, regulations, trade agreements, customs, norms, traditions that govern the actions and interactions of value chain actors. Therefore, value-chain development requires systems thinking.
- Effective operationalization of value chains may need value chain accelerators. Value chain accelerators are interventions across value chain nodes to ensure sustainable and effective functioning of the value chain process. The accelerators involve capacity building, knowledge management and research and documentation (Fig. 9 Haileslassie et al., 2014).

Critical thinking and discussion points:

- ✔ **Give examples of an irrigation commodity value chain and identify the different value chain nodes and key challenges at each node in the rift valley context.**
- ✔ **Discuss how the value chain approach and its implementation helps in developing efficient use of water and developing resilient landscapes (link to integration and optimization).**

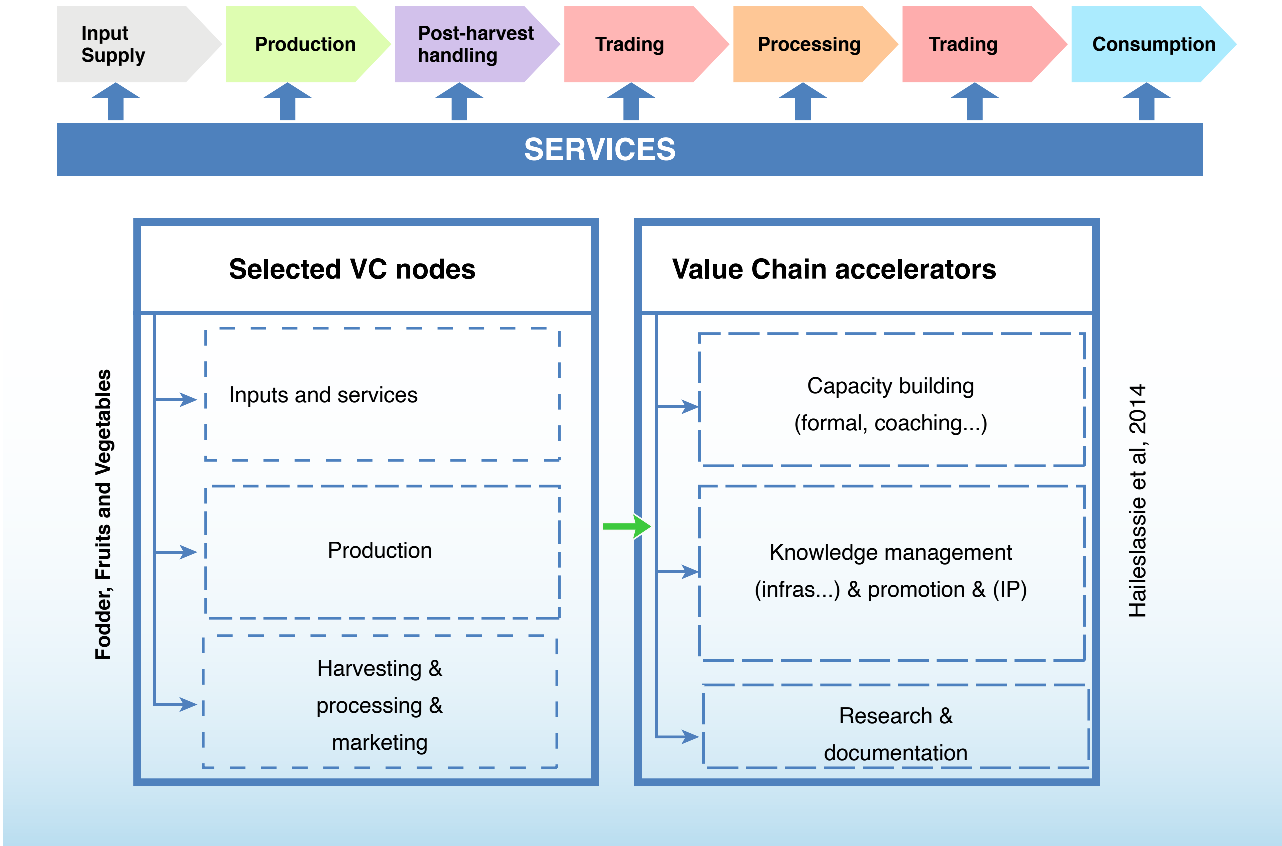
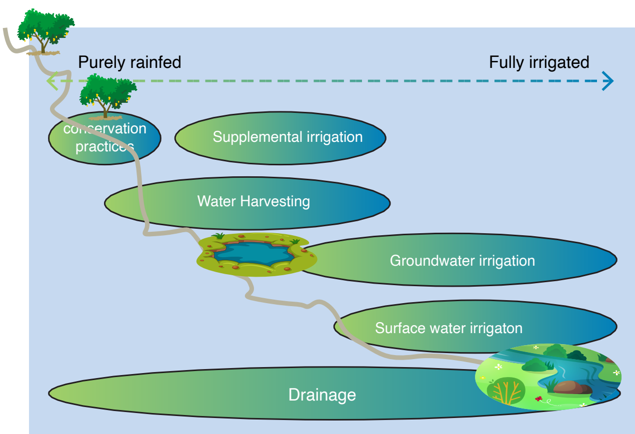


Figure 9: *value chain nodes and value chain accelerators as applied to irrigation.*

2.4. Rainfed-irrigation continuum and upstream – downstream interactions

Rainfed and irrigation systems at a landscape or watershed scale are interdependent units, although we give them different names to simplify management (Fig. 10) (Molden at al., 2007). In the central rift valley, rainfed agriculture is the most vulnerable production system to climate variability and extremes (e.g. highly variable rainfall, long dry season, recurrent drought, floods). Also, these rainfed systems in many cases are degraded and water stressed. This indicates the need to improve water management to build resilient landscapes. Currently the dryland systems, including the valley floor of the rift valley, are confronting several unprecedented risks and uncertainties. This involves risks related to climate change or risks related to flooding. In principle farmers are not passive observers of change in their environment. This is demonstrated through emerging accelerated farm-level irrigation development through pumps. Farm-water harvesting is continuously encouraged through development agents. Small to large-scale industrial investments are emerging in many landscapes of the rift valley. These incur competing uses and users of water. Ethiopian water resources policy mainly focuses on the economic value of water and this could make irrecoverable damage to ecosystems and social values. Enforcement requires carful exercise of water allocation and policy frameworks.



Source: IWMI (2007)

Figure 10: *Graphic illustration of the rainfed and irrigation continuum across landscapes.*

An integrated in-situ and ex-situ agricultural water management approach could be an option to minimizing surface runoff and increasing soil moisture (Haileslassie et al., 2013b). Moreover, better management of agricultural water in a landscape context supports recharge of shallow groundwater and would open an opportunity to practice irrigated agriculture at the middle and lower part of a landscape (Molden 2007). This is an example of integrating/ ensuring a rainfed irrigation continuum for sustainable agricultural production in landscapes (Fig. 10).

2.5. Agroforestry - integration of trees in agricultural landscape

Anthony (1997), describes agroforestry as a collective name for land-use systems and technologies where woody perennials are deliberately integrated on the same land-management units as agricultural crops and/or animals. It has some form of spatial arrangement or temporal sequence. Shem et al. (2016), suggest that there are both ecological and economical interactions between the different components of agroforestry systems (tree, crop and animal). Agroforestry is a dynamic ecological-based natural resources management system. Agroforestry systems are multifunctional systems that can provide a wide range of economic, sociocultural, and environmental benefits. Through the integration of trees, agricultural landscape production will be sustained, livelihoods will be diversified, and income will be increased (Fig. 11).

There are three main types of agroforestry systems: i) **agrisilvicultural systems** are a combination of crops and trees, such as alley cropping or home gardens; ii) **silvopastoral systems** combine forestry and grazing of domesticated animals on pastures, rangelands or on-farm; and iii) the three elements, namely trees, animals and crops, can be integrated in what are called **agrosylvopastoral** systems and are illustrated by home gardens involving animals as well as scattered trees on croplands used for grazing after harvests.

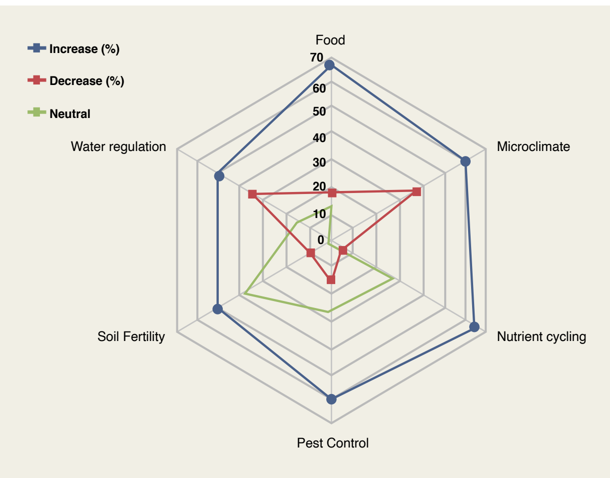


Figure 11: *Proportions (%) of ecosystem services that increase and decrease by trees in Sub-Saharan Africa (Shem et al., 2016).*

Shem et al. (2016) and Anthony (1997) illustrated that while trees affected some ecosystem services positively, they affected others negatively. Competition for nutrients, water and light are the most reported tradeoffs. But the effect depends on tree management as affected by the multi-functionality of tree species, their resource use efficiency and ability to favorably modify the microclimate for crops.

Critical thinking and discussion points:

- **Go back to your landscape in the previous module or draw a new one after better understanding from previous exercises and feedback and follow the steps.**
- **Define your boundary of a landscape as in previous exercise**
- **Draw your faming system clusters within the landscape (use your knowledge of altitude, rainfall temperature and availability of water). Make the boundary open.**
- **Within each of the faming systems, draw a hypothetical farm cluster assuming diversity in livelihood assets (e.g. high input intensive farms, off farm-based income farms, extensive farms)**
- **Show the rainfed and irrigation systems of your landscape which you might have mapped as interactive or independent systems. Show the continuum of the two systems and elaborate how maintaining the continuum would help building resilient agricultural landscape.**
- **Show the role of value chains in influencing the productive use of water landscape resilience between the different approaches.**

Module 3: Sustainable agricultural landscape transformation - pathways development

3.1. Agricultural sustainability in context

Sustainable agriculture focuses on increasing agricultural production while having minimal effects on the environment. This type of agriculture tries to find a good balance between the need for food production and the preservation of the ecological system within the environment. In addition to producing food, there are several overall goals associated with sustainable agriculture, including conserving water, reducing the use of fertilizers and pesticides, and promoting biodiversity in crops grown and in the ecosystem. Sustainable agriculture also focuses on maintaining economic stability of farms and helping farmers improve their techniques and quality of life. There are many farming strategies that help make agriculture more sustainable. Some of the most common techniques are included in Figure 12 (Tey et al., 2012), both in terms of what to do and what not to do, including the outcomes and their interactions.

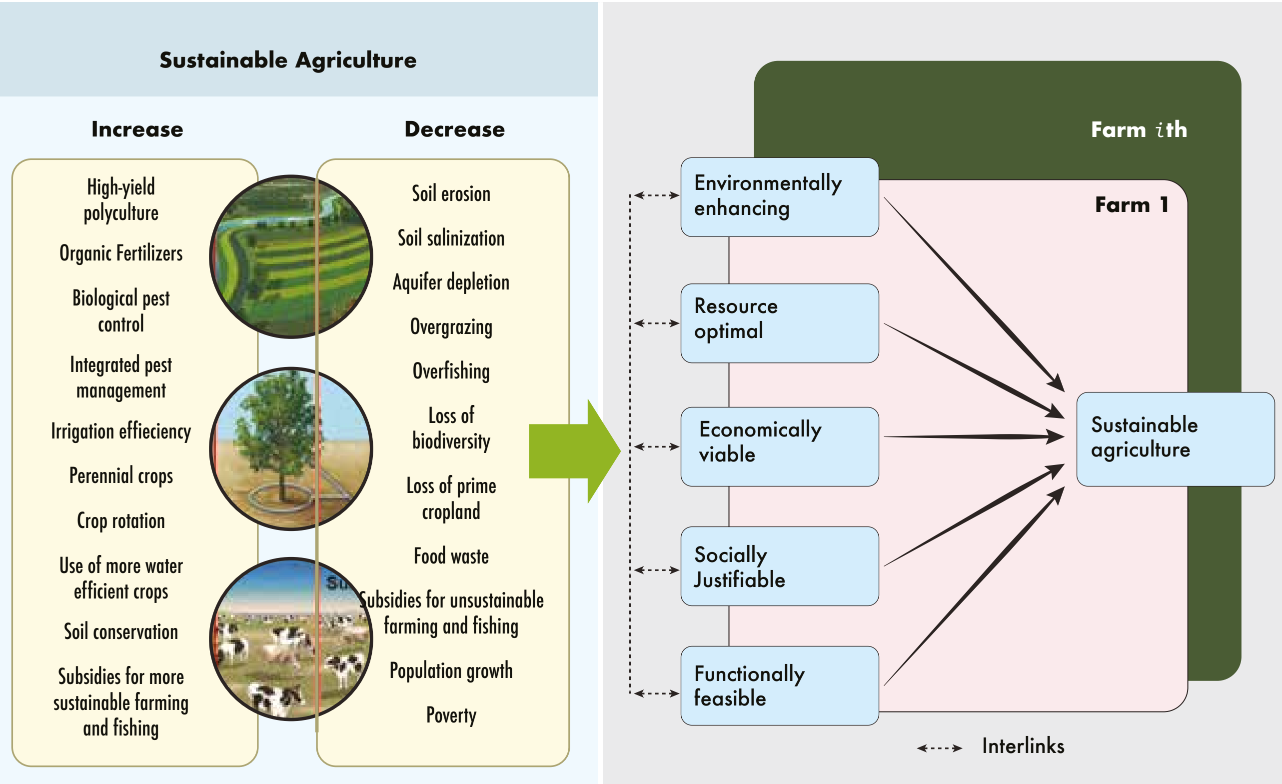


Figure 12: *Sustainable agriculture practices and outcomes*

[1] *Extracted from manuscript under development on sustainable agricultural intensification pathway (Haileslassie et al., unpublished)*

3.2. Measuring sustainability[1]

Sustainable agricultural intensification (SAI) requires indicators and associated metrics to track progress, assess trade-offs and identify synergies (Haileslassie et al. 2016; Smith et al. 2017). In this regard, Smith et al. (2017) organized indicators into five domains. These are productivity, economic sustainability, environmental sustainability, social sustainability and human wellbeing. Examples of each of these indicators are provided below:

1) Productivity is usually expressed in a variety of indicators and metrics including yield, input efficiency, water efficiency, and animal health.
2) Indicators for economic sustainability include agricultural income and crop value. Metrics of agricultural income at the field level include net income from agriculture, disposable income losses of agricultural income due to natural disaster or changes in total agricultural income.
3) Human wellbeing domains are food and nutrition security. This is the ability of smallholders to meet their own food needs and can be measured in terms of the net production of nutrients on the farm relative to the food needs of the farming household (The Montpelier Panel 2013).
4) Environmental sustainability includes biodiversity, carbon sequestration, soil erosion, nutrient dynamics, soil biological activity, and soil quality and in many cases productive uses of water (e.g. Haileslassie et al. 2016).
5) Example of indicators for social sustainability include information access and gender equity (Rai et al.; 2011; The Montpelier Panel, 2013).

Although the five domains of SAI indicators (productivity, economic sustainability, environmental sustainability, social sustainability, and human wellbeing) could potentially be adopted across scales, there is no such a consensus on type of indicators to use and monitor. Sustainability matrices and indicators are functions of time, space and the social dimension, making it difficult to have one common indicator across time and space. Indicator selection needs to be contextualized.

Critical thinking and discussion points:

- what are the different practices (good and bad), and indicators, in the context of the different agricultural system in the rift valley – disentangle system by irrigation, rainfed etc.
- what are the different sustainability pillars and their respective indicators and metrics in context of your landscape?
- Elaborate gender empowerment as one of the proxies to measure social sustainability

3.2.1. Conceptual pathways for sustainable agricultural intensification in landscapes

Increasing population and concurrent demand for more food, fiber and other agricultural products is one of the global challenges. Sustainable agricultural intensification can be an option to address this global challenge. However, a review of literature (e.g. Haileslassie et al., 2016; Mutyasira et al., 2018; Kumar et al., 2019) revealed that there could be several pathways for sustainable intensification within a landscape because of differences among farms and farming systems in terms of their farm structure and function (Fig. 13). Also, farms in a landscape differ in values and resources they share, for example water, land, market, climate and common property resources (Fig. 13). These resources define their economic and environmental sustainability dimension, while the social value they share (e.g. level of access to resources and wealth accumulation) is linked to their social sustainability dimension. Therefore, finding a common pathway that brings together interests of all actors in a system or landscape is usually difficult.

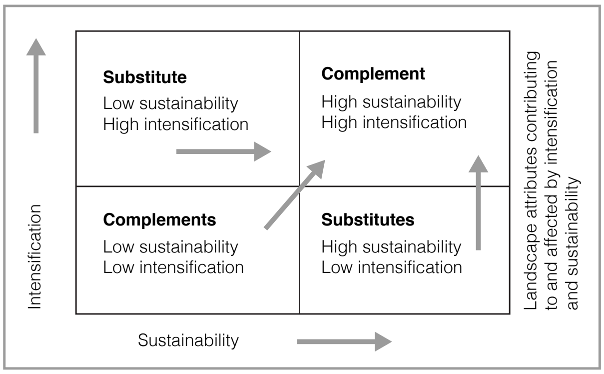


Figure 13. *Conceptual pathways for sustainable agricultural intensification.*

Critical thinking and discussion points:

- **Can you identify and assign attributes that best explain farms or communities or systems or landscapes in each of the quadrants**

3.2.2. Designing sustainable intensification pathways: understanding performance and targeting changes needed

This section focuses on delivering methodological frameworks to understand the context of sustainability assessment and to develop the intensification pathways. Our systemic approach outlines how to move from sustainability assessment per se to sustainable intensification pathways development by coupling the later to principles and approaches which enables complementarities and synergies of interventions. The overall framework proposed here (Fig. 14) aims at ensuring comprehensiveness and robustness of the evaluation and planning and supporting the decision-making process. The overall structure of the framework is constructed from four building blocks: (a) sustainable intensification indicators (Fig. 14a), (b) understanding performance of sustainable agricultural intensification measures (or metrics of sustainable intensification, Fig. 14b), (c) defining sustainable intensification pathways to bring the desired changes and managing trade-offs (Fig. 14 c), and (d) principles and approaches enabling synergies and complementarities of interventions (Fig. 14 d).

When developing indicators of sustainable intensification (SI) of agricultural landscapes, it is important to first understand the existing landscape of indicators, indices, and datasets at the nexus of agricultural landscape components and addressing the target domains and scales of interest. Here important guiding questions could be: a) what indices and indicators exists about SI of agricultural landscapes? b) how important are they and can they reflect local community perception? c) What appropriate datasets already exist? d) what can be learned and leveraged from these existing indices, indicators, and datasets? and e) what is the available resources?

Literature including Smith et al. (2017) and Haileslassie et al. (2016) can be used to identify generic indicators and matrices contributing to each of these domains. The key step is to contextualize this based on desk work, key stakeholder consultation and expert knowledge of the site (Fig. 14 B). Table 1 depicts generic indicators proposed to understand system sustainability and changes needed. The list is developed based on generic indicators suggested by Smith et al. (2017) and Haileslassie et al. (2016). This can be substantiated by expert knowledge of key opportunities and challenges. There is space to involve farmers. During the first site-tour, farmers will be asked to suggest additional indicators and undertake pairwise ranking. In efforts of understanding changes needed, the next step is to answer question on status of sustainability indicators by exploring deeper the performances of each of these indicators under current practices (Fig. 14B).

A landscape is diverse both biophysically and socially and so are farm and faming systems (Haileslassie et al., 2016). The first approach in handling this heterogeneity and making recommendations context specific is to cluster farms and landscapes to homogeneous groups. Different techniques are available to deal with the heterogeneity of farmers: for example, a qualitative participatory typology based on informal group sessions and interviews with local stakeholders. A landscape typology can be developed using traditional altitudinal belts or alternatively farming systems as proxy indicators *(highland, midland, lowland; rainfed based highland, irrigation based lowland farming)*. Farms nested in the landscape can be clustered using a participatory method *[resources better off, medium or poor* (Participatory Learning and Action)]. The advantage of participatory methods is that they also include additional groups of females and "landless" farmers, who are important in the communities. We may use radar charts and similar techniques to display the relative importance of the different SIs across landscape position and farmers' group.

For poor performing indicators we will explore further through consultations with stakeholders. Literature review can also enrich this component on the potential and actual performances of each of the indicator, for example yield gap either within the system and from practices elsewhere with similar system setting and practices.

Critical thinking and discussion points:

- Can you identify indicators in the context of your earlier landscape and faming systems?
- Can you undertake pairwise ranking exercises?

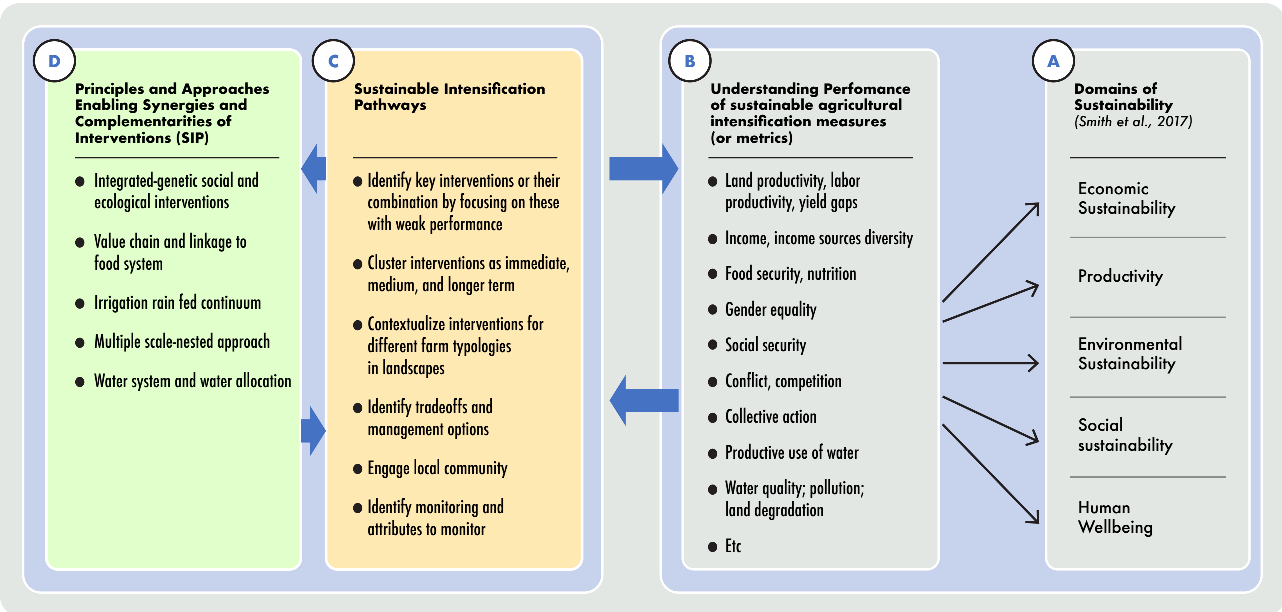


Figure 14. *Methodological framework to assess intensification and develop sustainable agricultural intensification pathways.*

3.2.3. Systematic identification of actions required

Once the type and importance of constraints and their causes are understood, it is important to systematically identify interventions to turn around the current performance of the selected indicators (Fig. 14 c). This section will enhance the understanding of the spatial (plot, farm, system, watershed, landscape) and temporal (immediate, midterm and longer term) scales where interventions to address the constraints are required. Overall an important aspect is to look at how these context-specific interventions would improve the performance of the different indicators and how they individually and as a group bring about the desired changes in the target indicators and the sustainability pillars (Fig. 14 C). Literature review could provide insight of how these different interventions contribute to one or more indicators and understanding their trade-offs. The base for selection of the different interventions is the current practices, the level of resource endowment and people's choice (Fig. 15). In this line, consultations with key stakeholders could support the combination of different intervention and their time scale (Fig.15). Other important aspects include to check the policy priority and institutions in place to help achieving the targets.

Table 1: *Generic indicators and indices proposed for understanding performance of sustainability domain and targeting changes*

Target domains	Generic indicators	Units	Importance*	Pairwise comparison	Scale	Sources of information
Economic sustainability	Agricultural income	USD/Head	H	?	Farm	Survey
	Crop value	USD/kg	M	?	Farm	Survey
	Income sources diversity	#incsources/HH	M	?	Farm	Survey
	Income stability	% changes between years	H	?	Farm	Survey
Productivity	Yield	(kg/ha)	H	?	Farm	Survey/literature
	Water use efficiency	kgm-3	L	?	Farm	Survey/literature
	Input efficiency	Kg input/kg return	L	?	Farm	Survey/literature
	Cropping intensity	# crop/yr.	H	?	Farm	Survey/literature
	Yield gaps	% deviation from potential	L	?	Farm/LS	Survey/literature
Environmental sustainability	Biodiversity	# crops on farm	L	?	Farm/LS	Survey/literature
	Agrochemical inputs	kg/ha	L	?	farm	Survey/literature
	Erosion	ton/ha	H	?	Farm/LS	Survey/literature
	Level of water pollution	Level of pollution risks	H	?	LS	Survey/literature
	Nutrient dynamics	% manure recycled	H	?	Farm	Survey/literature
	Land use change	% change to agriculture	M	?	Farm/LS	Survey/literature
Social sustainability	Information access	Radio/TV/Mobile	M	?	Farm	Survey/literature
	Gender equity/ social security	Access to resources, decision making	H	?	Farm	Survey/literature
	Access to credit	% having access to credit	H	?	Farm	Survey/literature
	Level of poverty	Above or below poverty line	H	?	Farm	Survey/literature
	Conflict over resources	Frequency and nature of conflict	H	?	LS	Survey/literature
Human wellbeing	Food and nutrition security	# of food insecure months	H	?	Farm	Survey/literature
	Risk	Scale of water related risks (drought, flood)	H	?	Farm	Survey/literature

**Relevance is indicated based on expert's knowledge: L stands for low, M for medium and H for high. Under scale LS stands for landscape (After Smith et al., 2017).*

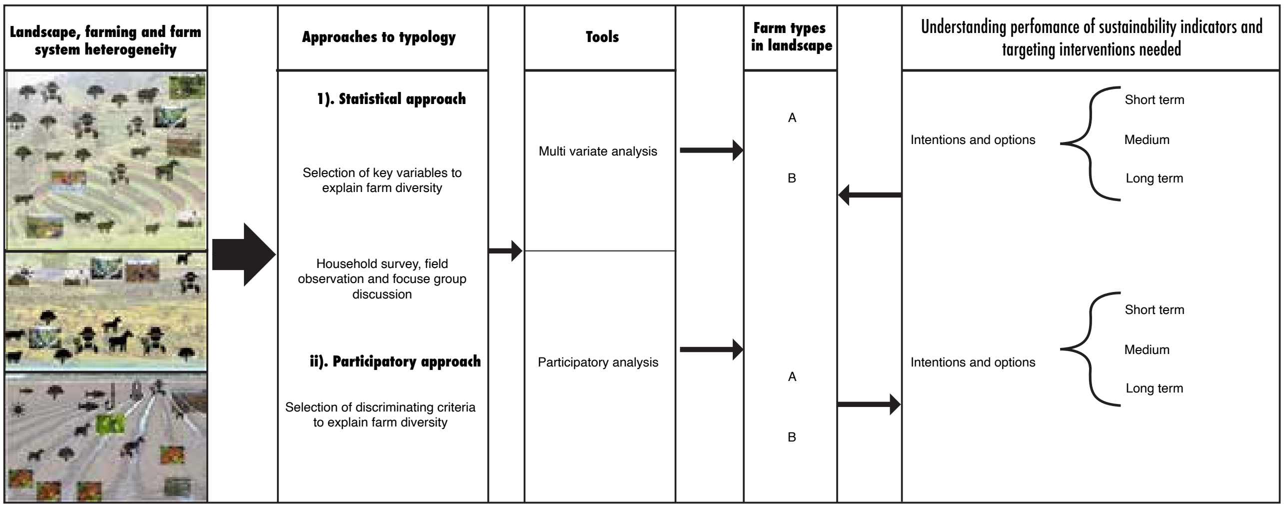


***Figure 15:** Schematic diagram illustrating how the process of farm typology/in different landscape positions can be targeted by different interventions*

Critical thinking and discussion points:

- what type of innovation would be principally required to address the constraints and how would these innovations be integrated and implemented in a farm or landscape.
- what are the points of linking of these interventions to the overall food system.
- what are the potential trade-offs and how can they be managed (scenarios); and
- understanding farmers 'choice' or interest.

Module 4: Water efficient and resilient landscape management technologies

There are several in-situ and ex-situ agricultural water management technologies tested for Ethiopian conditions. Figure 16 illustrates sources of water, mode of storage and principal use of water. Water lifting technologies enable tapping into ground water resources and help to mitigate climate change. From experiments conducted by IWMI using 10 sets of solar pumps in the Ethiopian dryland system (Rift Valley) it was concluded that solar pumps attached to drip systems have significantly higher net present value compared to other technologies. Given the water savings from the lifting and application techniques, the technology would also help to save water which provides opportunity to irrigate more areas and thus build climate change resilient landscapes.

Water harvesting is an important entry point to improve the productivity of dryland systems. This could take the form of in-situ or ex-situ. Use of several technologies including subsurface soil hard pan breaking technologies have showed promising results in terms of reducing runoff and soil loss and increasing infiltration and the overall crop yield. Technologies such as hillside micro-basins have proved to work well, particularly on rangelands (https://wocatpedia.net/wiki).

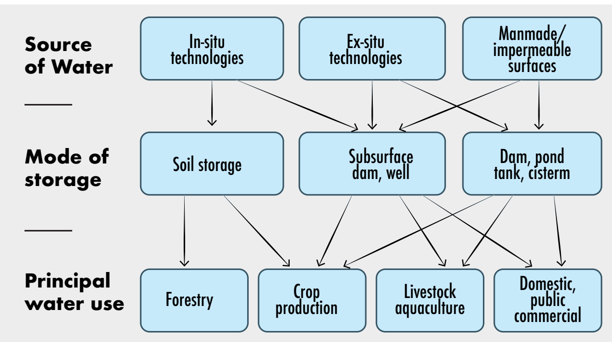


Figure 16: *Sources of water, mode of storage and principal use of water for different water management technologies.*

Farm ponds and several micro-dams, despite positive impacts have several challenges, including siltation (Gebremedhin et al., 2016). For example, seepage loss on the net harvested water is very high and the irrigated area can be increased considerably if proper water saving and utilization measures and mechanisms are implemented. The current situation illustrates the diversity of the impacts and the need to improve water harvesting efforts, particularly related to macro-ponds and micro-dams. These efforts must also take future water demand into account and micro-watershed level water allocation is an important ingredient of the planning process. While initiating farm ponds in dryland systems (for example in the rift valley), techniques to alleviate these hurdles must be in place.

4.1. In-situ water harvesting and soil and water conservation technologies

Rainwater harvesting for infiltration, also known as in-situ water harvesting, is a practice in which rainwater uptake in soils is increased through the soil surface, rooting system, and groundwater. The soil effectively acts as the storage agent, which improves water holding capacity and fertility and reduces risks of soil loss and erosion. Common examples of water harvesting practices include trenches, terracing, pitting and conservation tillage. Due to variable and unpredictable weather patterns these technologies have served as important water sources for agriculture for centuries (Shibeshi et al., 2016). They play an important role in climate change adaptation due to increases in unpredictable weather patterns. Apart from their predominant function of improving cropland and vegetation, they can also help ensure sustainable water supplies for livestock or domestic use through improved recharge of nearby water-flows or ponds, as well as groundwater. More specifically, the benefits of in-situ water management includes increased infiltration and recharge [Erkossa et al., 2020 (Fig. 17)], soil fertility and water holding capacity of soils and reduced risk of soil erosion and loss (Fig. 17). Table 2 indicates types, purpose, and management options of in-situ water management technologies.

Continuous cultivation of land accelerates migration of fine clay particles down the profile which accumulates and creates an impenetrable layer called hard pan. Hard pans limit percolation of water into the soil system, the water is thus usually lost as surface runoff. This could also contribute to topsoil erosion and limited availability of shallow groundwater downstream.

***Table 2:** Examples of in situ-water management technologies.*

Soil-water management strategy	Purpose	Management Options	Management type
In-situ water harvesting systems	Maximize infiltration capacity of the soil	Improve topsoil conditions	• Protective surface cover: cover crops, residue, mulches against disruptive action of raindrops • No or reduced soil disturbance by tillage • Conservation agriculture • Soil amendments • Fallowing under cover crops or natural vegetation • Temporary closure of grazing land and subsequent protection
		Improve subsoil conditions	• Deep tillage: subsoiler or paraplough to break-up water restricting layers
	Slow down and/or impede runoff	Increase surface roughness	• Surface cover: cover crops, residue, mulches, geotextiles • Conservation agriculture
		Apply physical structures across slope or along countour	• Terracing: level terraces, bench terraces, Zingg, fanya juu, murundum, contour bund, graded channel terrace, orchard terrace

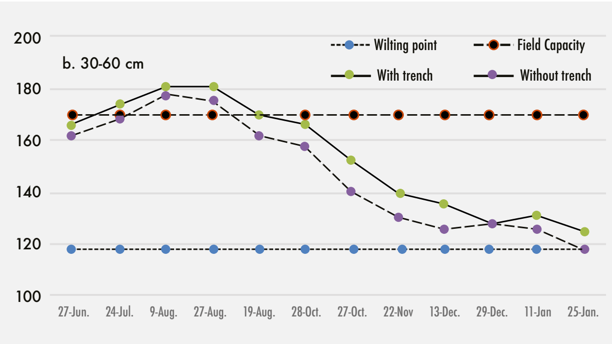


***Figure 17:** Effects of trenches on soil moisture dynamics across the cropping season in upper Awash basin.*

The experiment was set out to compare different options of breaking hard pans. The options involve the use of (i) no-till (NT), no ploughing; (ii) conventional tillage (CT), plots tilled three times using oxen driven Maresha (Ethiopian traditional plough) , (iii) deep tillage (DT), manual digging up to 60 cm using a mattock and (iv) Berken tillage (BT), plots tilled three times using an oxen driven Berken plough [locally innovated plough type and Bi-T for biological treatment using pigeon pea (Muche et al., 2017). The penetration resistance as indicated on Figure 19 has

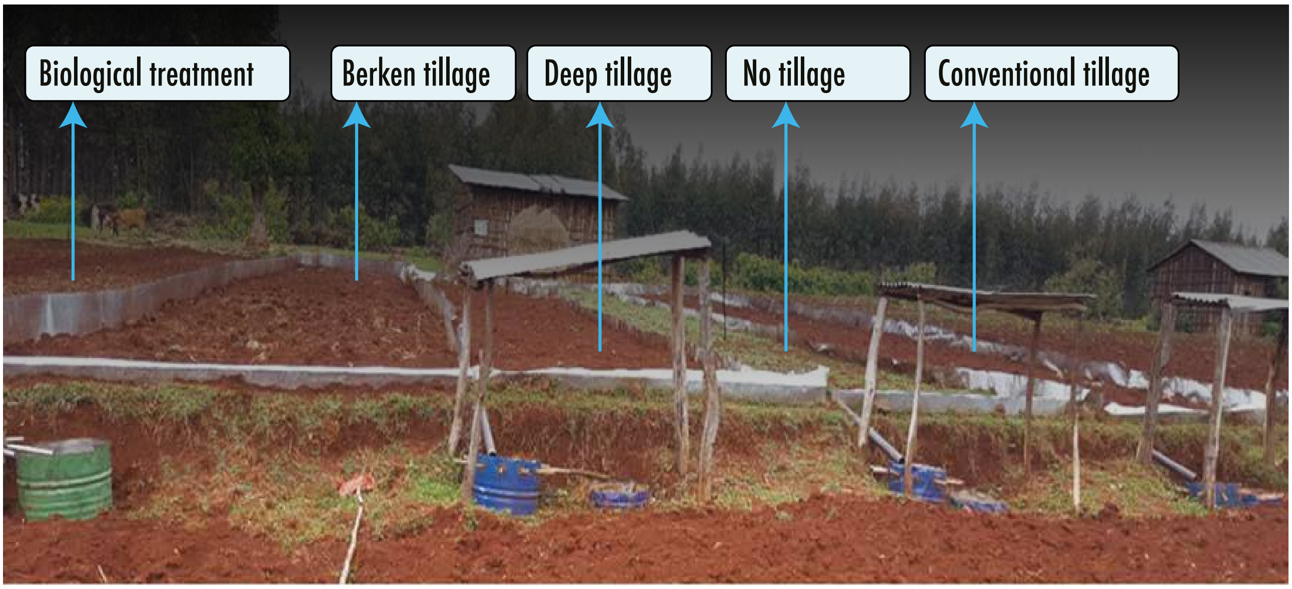


***Figure 18:** Sets of experiments on how different depth of tillage and breaking of the hard pan affects soil penetration resistance, infiltration, runoff, erosion and biomass yield.*

significantly dropped for the 20-40 cm depth and infiltration capacity was significantly improved by 50%, 46% and 30% due to the application of deep, Berken and biological systems, respectively (Fig. 19). As indicated in Figure 20, the trend in infiltration capacity was similar to the gain in infiltration, and DT and BT showed more promising values.

The example (Fig. 18-21) illustrates the experimental layout (from the work of IWMI and partners), and how deep tillage breaks the hard pan created and how it increases infiltration.

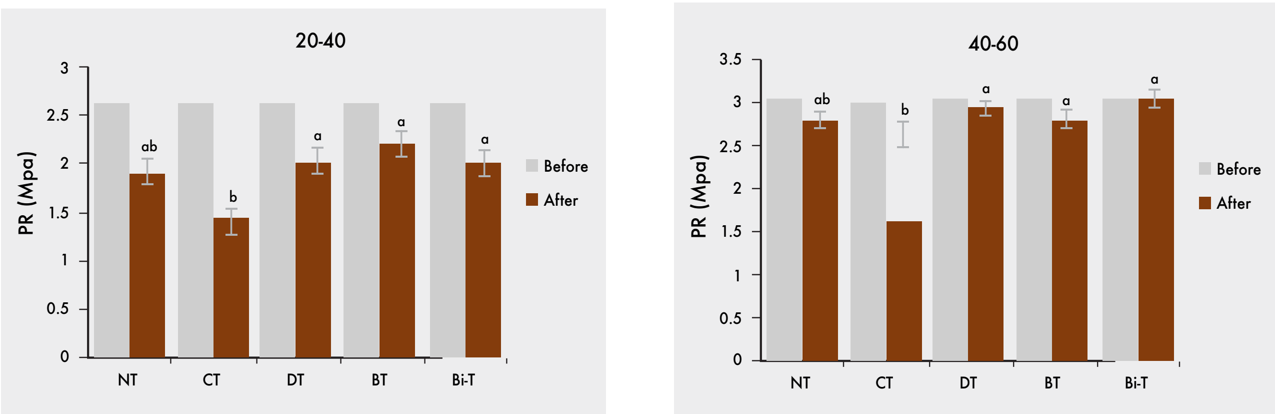
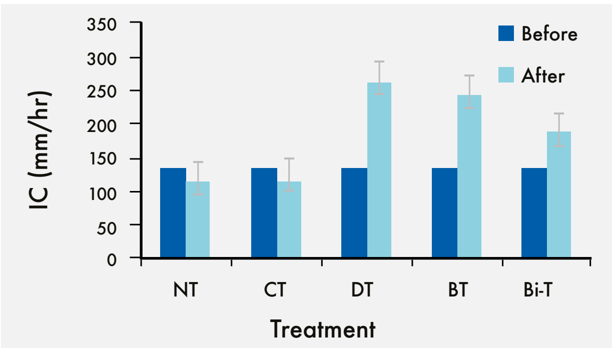
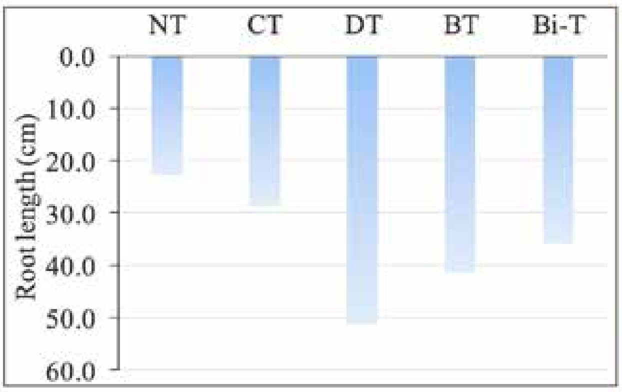


***Figure 19:** Penetration resistance under different depth of tillage (BT is for berken tillage, DT is*



Treatments (T)	Runoff (mm)	Soil loss (t ha^{-1})
NT	98.8±27.6^{a}	6.7±1.1^{a}
CT	71.4±13.6^{a}	5.5±1.0^{b}
DT	28.5±4.9^{b}	2.6±0.6^{c}
BT	33.5±6.2^{b}	2.6±0.6^{c}
Bi-T	47.6±8.4^{ab}	3.8±0.7^{bc}

***Figure 20:** Effects of different depth of tillage on infiltration, run off and soil loss*



Treatment	Biomass (t ha^{-1})	Yield (t ha^{-1})
NT	11.7^{b}	2.68^{c}
CT	15.1^{ab}	3.83^{b}
DT	15.4^{ab}	3.76^{b}
BT	22.4^{a}	3.98^{ab}
Bi-T	16.7^{ab}	4.8^{a}
CV (%)	44.9	18.67
LSD	9.9	0.9

***Figure 21:** Effects of different depth of tillage on root length of plant, biomass and crop yield*

4.2. Ex-situ water harvesting technologies

In ex-situ systems, water is not collected in the soil as the storage medium. Water is stored in natural or artificial reservoirs with different dimensions, i.e. wells, ponds or cisterns, for irrigation purposes or for domestic use. In contrast to the in-situ systems, the surface of storage infrastructure has little or no infiltration capacity (Fig. 22). Small-scale basins or on rooftops are common methods of collection of rainwater. The latter is mainly collected for domestic purposes but can also be used for small kitchen gardens. Ex-situ rainwater harvesting can reduce pressure on surrounding surface water and groundwater resources, as well as peak flows and flow durations.

In summary:

- Application of deep and Berken tillage systems on farmlands are effective in terms of increasing the infiltration rate.
- Reduction of surface runoff from deep and berken tillage systems reduce soil loss.
- Improved tillage systems have positive impact on root length and grain yield.
- Therefore, proper implementation of berken and deep tillage system will have a far-reaching impact on land productivity.

Figure 22: *Roof water harvesting for supplemental irrigation of Alfalfa and rope and washer pump applied for lifting of ground water to irrigate Alfalfa (SNNPR) - Photo credit Amare Haileslassie.*

It is commonly agreed that water harvesting systems are beneficial. Experiences suggest that sustainable and locally adapted rainwater harvesting systems can contribute to food security and adaptation to climate change and improve the livelihood of farmers. Rainwater harvesting can be an alternative and/or complementary method to large-scale water withdrawals and reduce negative impacts on ecosystem services, such as erosion. In addition, small-scale rainwater harvesting systems can yield a higher amount of collected water than large dams, as evaporation and water losses are reduced.

4.3. Estimating runoff for surface water harvesting

Estimating harvestable runoff is an important step in ex-situ water capturing techniques. There are a number of methods available depending on water sources (e.g. roof, road and surface) and level of precision required. Here we will focus on the source runoff and the most commonly applied calculation methods. One of the most applied technique is the soil conservation service (SCS) runoff curve number method (Yongping, 2001)

A) **The soil conservation service (SCS) Runoff Curve Number (CN) method:** The SCS runoff equation can be illustrated as given in Eq 1

$$Q = \frac{(P-Ia)2}{P-Ia+S} \text{ ……………………………….(Eq 1)}$$

where
Q = runoff (in) P = rainfall (in) S = potential maximum retention after runoff begins (in) and Ia = initial abstraction (in). Initial abstraction (Ia) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, Ia was found to be approximated by the following empirical equation:

$$Ia=0.2S \text{ ……………………………..(Eq 2)}$$

By removing Ia as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation 2 into equation 1 gives:

$$Q = \frac{(P-0.2s)2}{P+0.8S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(Eq\ 3)$$

S is related to the soil and cover conditions of the watershed through the CN (Fig. 23).

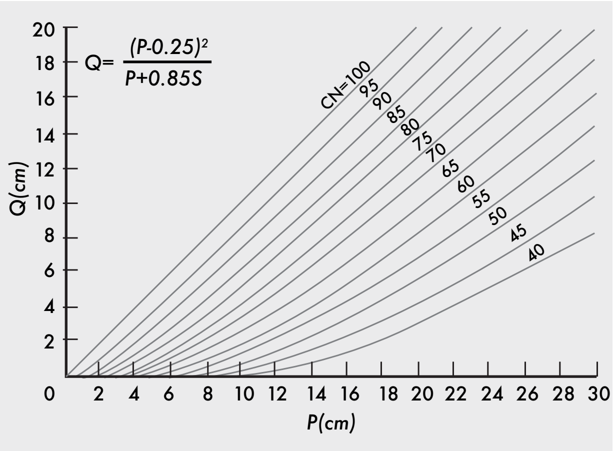


Figure 23: *SCS run off curve number*

CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.Eq\ 4$$

B) Rational Method: Another very simplified method of estimating run off is the rational method. The **Rational Method** can be illustrated by the following equation and can be applied in data scarce system and when less level of precision required

$$Q=CIA\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.Eq\ 5$$

Where: Q = peak flow (m^3/hr) C = runoff coefficient (dimensionless) I = precipitation intensity (m/hr) A = effective drainage area (m^2)

c) Roof water harvesting method: This is the most common practice in urban areas for household water supply and small family garden. The runoff estimation is illustrated by Eq 6

$$Q = PA$$

Where: Q is a harvestable water, average annual P (m) and A is roof area in M^2

Critical thinking and discussion points:

- **Assume a rainfall value of 500 mm on micro catchment of 1000 m2. Estimate the total annually harvestable run off and discuss options to use.**
- **Assume a rainfall of the same magnitude as above and roof area of 40 m2. Estimate the harvestable water and discuss best and effecting way to use.**
- **If all farm households in a catchment /landscape would be able to harvest all drop of rainfall what would happen? Remember systems as open and material flows in a system. remember upstream downstream issues and rainfed irrigation continuum we discussed earlier. In view of this, critically discuss why system management in isolation is a risk.**

Module 5: Lifting, conveyance, and on-farm water application

5.1. Solar pumps

5.1.1 Why solar pumps

Improved supply of and access to clean water is one of the SDG 6 targets. Supply of water for drinking or irrigation purposes also remains an issue to be solved in many remote areas of Ethiopia. Under the current status of access to safe drinking water and water for domestic consumption, even addressing COVID-19 pandemic would be a challenge. This requires a reliable source of energy that can pump water to usable heights. Currently, diesel generators are commonly used to provide pumping power. However, they have several disadvantages involving pollution and the energy sources; oil, is not a renewable resource and as the global reserves diminish the price is increasing. Secondly, there is a continued complaint of adulteration by farmers in remote locations and this is posing a significant threat to a consistent water supply. Finally, diesel generators require regular operation and maintenance as well as a replacement.

PV-powered water pumps (PVP) (Fig. 24) offer a promising alternative in relation to the drawback of diesel pumps. Powered by renewable solar energy, they are not subject to price hikes. While supply can vary due to cloudy periods, long-term consistency of supply is ensured as the time of greatest water demand usually coincides with the maximum available solar energy. Furthermore, the absence of moving parts offers high reliability at little maintenance requirements. Ethiopia, located in the tropics, has high solar radiation which makes the technology very relevant. Despite these advantages the uptake of PVP remains low mainly because of cost and market access. Both technology options require a replacement of the pump after 10 years. The costs for replacing the diesel generator are nearly equal to the cost of an inverter. In terms of maintenance, diesel systems are more expensive with an approximate 6 % of installed hardware costs p.a. compared to 1 % for

Figure 24: *Solar pump linked to drip system in central rift valley (Photo credit: Amare Haileslassie).*

PV-powered pumps due to repairs and auxiliary materials. Figure 25 illustrates the result of life cycle assessment of the two technologies. The key difference in life-cycle-costs, however, is due to operating costs. These consist of costs for personnel (3 times higher for DPP compared to PVP) and fuel. The costs of the latter for DPP outweigh PVP-related operating costs by a factor of 20 despite a moderate diesel price at 0.61 €/L and price-escalation calculated at 2 %. Annualized, the life cycle of the different technology choices is presented in Figure 25.

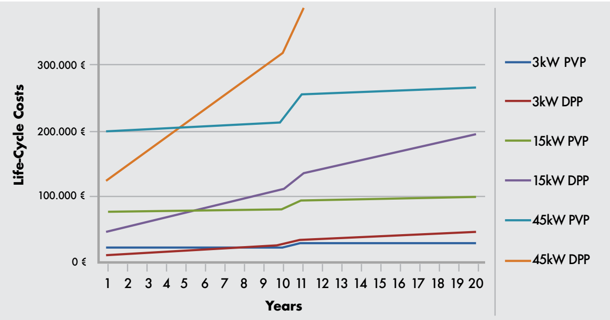


Figure 25: *Life cycle assessment of cost of diesel pump and PVP by their power.*

As the amount of water supplied and other costs (such as, labor, agronomic practices and related costs) differ by irrigation method, it helps to do a comparative analysis between the different water application methods. For example, the drip system would provide precision in water application leading to a decreased water loss from wind and evaporation, hence the long-term advantages would be lower energy, operating costs and water savings.

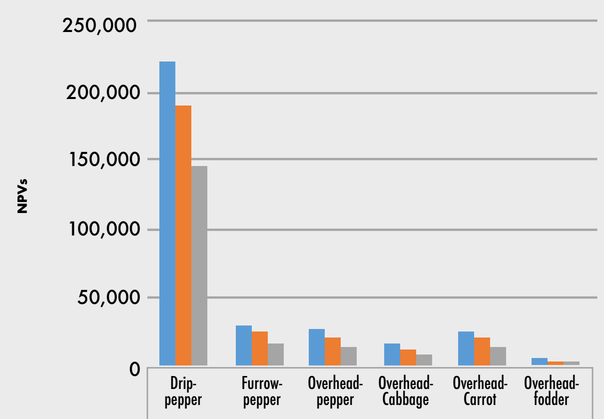
Results /Evidence: The overall result shows that investment in solar pumps is profitable, given that a minimum land size is available. As solar energy is a clean (zero-carbon) energy, the technology is very much consistent with the Ethiopian Government Climate Resilient Green Economy (CRGE) strategy. The profitability of the technology depends on crop type and water delivery system where the drip system was found superior to the furrow and overhead systems. Our data also shows that land size matters implying that a minimum land size is required for a viable investment in solar pump irrigation, but the minimum required land size itself depends on different factors, including type of water application system, crop type, discount rate and location. Because access to affordable financing is crucial for small-holder farmers, microfinance institutions can serve as a more reliable source of finance than the formal banking system. Although high initial investment cost is a potential barrier for smallholder farmers to adopt the technology, cost sharing can be a solution, especially if additional investment is made in drip systems where land size can increase to about half a hectare. Moreover, partnerships between key actors including rural financial institutions are essential for a positive outcome of investment in solar pumps. While one can argue that commercialization is essential for sustainable market growth, targeted subsidies are needed at early stages until competitive prices are reached. In general, a solar pumping system has many advantages including its negligible operating cost. Because there is no fuel required for the pump, such as electricity or diesel, the operating cost is minimal. A well-designed solar pump requires little maintenance beyond cleaning of the panels once a week.

Figure 26: *Water application system tested, for solar pump illustrated in Figure 25 (left over head application, middle furrow and left drip system) (Photo credit: Amare Haileslassie).*

5.1.2. Example of demonstration of solar pump in Ethiopia

The International Water Management Institute (IWMI), through the Livestock and Irrigation Value Chain (LIVES) and Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) projects has piloted eight solar pumps, for smallholder irrigation with selected farm households in Oromia and the SNNP regions in the rift valley basin. The aim of the pilot was to demonstrate and test whether solar pumps can provide smallholder farmers with an affordable and sustainable irrigation water pumping. Solar pump panels capture the sunlight and convert it into electricity which drives the pump.

However, the technology has some limitations including: i) the technology piloted is not suitable for large scale commercial irrigated farms unless the capacity is augmented by adding more panels which in turn increases the investment cost, ii) the water yield of the solar pump changes according to the sunlight. It is highest around noon and least in the early morning and evening. However, for countries like Ethiopia located on the equator with long (about 10) hours of sunlight per day, this problem is less likely to be a limiting factor. We recommend that attention should be given to the system of irrigation water distribution and application to the crops. For example, our pilot experiment shows that when solar pumps are supplemented with a drip system, the size of irrigable land is almost doubled as compared to furrow and overhead irrigation and minimizes water loss and thus show higher net present value (Fig. 27). Equally important is its effect of reduced labor use per hectare.



	Drip-pepper	Furrow-pepper	Overhead-pepper	Overhead-Cabbage	Overhead-Carrot	Overhead-fodder
Discount rate (15%)	221294	30323	27061	16889	25817	4626
Discount rate (15%)	191100	25532	22464	13587	21378	2885
Discount rate (15%)	145670	18375	15619	8696	14772	354

Figure 27: *Profitability analysis of solar pumps.*

Critical thinking and discussion points:

- **Discuss the different advantages and disadvantages of different water lifting systems.**
- **Discuss each of the different water application techniques (drip, furrow and overhead) .**

5.2. Drip system

5.2.1. General

Drip irrigation is one of the most efficient methods of irrigation today. It delivers water at the plant location, frequently and at a volume of water approaching the consumptive use of the plant. The unproductive depletion (evaporative loss) is minimal as drip system water application is at the root zone and frequent, and it therefore maintains an optimum moisture level in the soil. The term “trickle” and “drip” are interchangeably used to describe such a system. The system delivers water by a pipe distribution network under low pressure (usually less than 40 m head). Water distribution and application in the field is by a small diameter flexible plastic lateral pipes (LDPE) with devices called ‘emitters’ or ‘drippers’ connected at selected spacings. Drip systems are usually, most suitable in areas where water is scarce. It is also the preferred water application technique under high-value crops or in areas where topographical and other conditions might preclude the successful use of other types of irrigation systems.

Some of the advantages of drip irrigation systems are that they save water, fertilizers, operating costs and reduce weed infestation due to wetting of lesser soil volume. They also enhance plant growth and yield as the soil volume is always in near optimum conditions. As water is only applied at localized places, it is a suitable system for irrigating leafy vegetables. Further, as the application is at or near to the plant location, there is more control of water by the system; it avoids sensitivity to wind, evaporation from soil and plant canopy, and leaf diseases and leaf burns. Drip systems have also several agronomical and agro-technical advantages. Due to partial wetting of the soil, it suppresses weed growth and reduces compaction of the soil. The system can be operated with less energy and operating cost. The system enables application of liquid fertilier and pesticides with water.

Disadvantages of drip systems include that the emitters are prone to clogging unless the water is filtered before it gets into the system. The lateral pipes are prone to mechanical and rodents’ damages. The system has no influence on the microclimate unlike the sprinkler system. As the application is more frequent, crop damage is more likely if irrigation is interrupted. For optimum crop growth, drip irrigation is suitable under the following conditions.

- Drip irrigation is adaptable to any farmable slope, whether uniform or undulating. The lateral pipes supplying water to the drippers should always be laid out along the land contour whenever possible. This will minimize the pressure variation among drippers and provide uniform irrigation.
- A good clean supply of water, free of suspended sediments, is required to avoid cloggig of drippers.
- Drip irrigation is suited for most row and tree crops.

- The drip system is best suited to sandy soils with high infiltration rates although it is adaptable to most soils due to possibility of a more frequent application of water than surface and sprinkler systems.

5.2.2. Family drip system

Drip irrigation systems are classified into surface systems, subsurface systems, overhead systems and bubbler systems. The most used system in sub-Saharan Africa is the family drip system and it is usually of surface type. A surface drip system is a system in which drippers and laterals are laid on the soil surface (Figure 28). The commonly used drippers in this system are online drippers (pressure compensating or non-compensating), in-line drippers and microtubes. The choice of these drippers depends on the type of crop, topography, availablity of labour, and soil type. This system is the most poular and therefore discussed in this guide. To support adoption of drip systems by the small farmers, a surface system that is low-cost, low-tech, low-pressure (gravity) drip systems are introduced by NGOs like the International Development Enetrprice (iDE) in developing countries in Africa and Asia. They are family drip systems that come with a complete kit for irrigating areas up to 500m². A pump is not required. The water source is an elevated water tank (reservoir) that serves as a pressure regulator and fertilizer injection point.

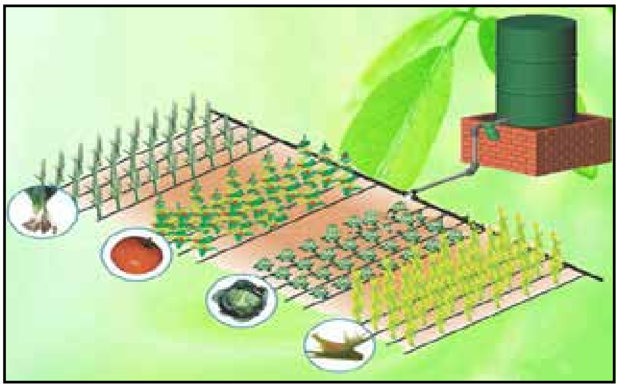


Figure 28: *Model family surface drip system.*

Subsurface drip irrigation (SDI) is the irrigation of crops through buried lateral pipes containing embedded emitters located at regular spacings. There are a wide variety of configurations and equipment used, however, drip tubes are typically located 15 to 25 cm below the soil surface. SDI is most widely used for the irrigation of both annual row crops, and field crops in the USA and permanent crops in Israel. Due to the high initial cost and intensive management requirement, its adoption has, however, proceeded slowly.

5.2.3. Crop Water Requirements, ETc

The amount of water which evaporates from wet soils and plant surfaces together with the plant transpiration is called evapotranspiration (ET). Its value is largely determined by climate factors, such as solar radiation, temperature, humidity and wind, and by the environment. Out of the total ET, evaporation accounts for about 10 percent and plant transpiration for the remaining 90 percent. Crop water requirements encompass the total amount of water used in evapotranspiration. Alternative approaches for estimating the evapotranspiration include the radiation, Penman and pan methods. Reference evapotranspiration (ETo) represents the rate of evapotranspiration of green grass under ideal conditions, 8-15 cm tall, with extensive vegetative cover completely shading the ground. It is expressed as a mean value in mm per day over a period of 10 to 30 days. The most practical method for determining ETo is the pan evaporation method. Although there are computer-based estimations of ETo, because of its practicality, in this manual, we focus only on the pan evaporation method (Fig. 29). This approach combines the effects of temperature, humidity, wind speed and sunshine. One of the best known pans are the Class A evaporation pan (circular- Fig. 30). The evaporation from the pan is very near to the evapotranspiration of grass that is taken as an index of ETo for calculation purposes. The pan direct readings (Epan) are related to the ETo with the aid of the pan coefficient (Kp), which depends on the type of pan, its location (surroundings with or without ground cover vegetation) and the climate (humidity and wind speed). Hence,

$$ET_O = E_P \, x \, K_P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .Eq\ 6$$

Where,

ET_o = Reference evapotranspiration, mm
E_p = Pan evaporation, mm
k_p = Pan coefficient

Figure 29: *Class A pan.*

For the Class A pan, the average kpan is 0.70. In order to relate ETo to crop water requirements (ETc), the specific crop coefficient (kc) must be determined:

$$ET_C = E_O \, x \, K_C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .Eq\ 7$$

Where,

ET_c = Evapotranspiration demand of the crop, mm
k_c = Crop coefficient

The crop coefficient (kc) depends on the crop leaf area and its roughness, the stage of growth, the growing season and the prevailing weather conditions (Fig. 30). There are normally four stages of plant growth – the initial stage, the development stage, the mid-season stage and the late season stage. Table 3 presents the kc values for different crops at various growth stages.

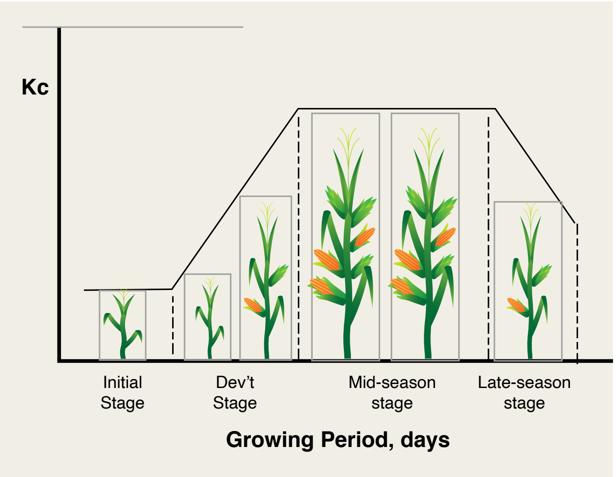


Figure 30: *Crop coefficient curve.*

Critical thinking and discussion points:

- **From local class A weather station, you have an average pan evaporation reading of 1500 mm. Estimate the ETo for the circular pan.**
- **Estimate the crop water requirement of young bananas and repeat the same exercise for lettuce.**
- **What should be the size of your water harvesting pond under exercise (ex-situ water harvesting) to grow bananas on 10m2? Repeat the same excise for lettuce**

Table 3: *kc values for different crops at various growth stages.*

Crop	Initial	Crop development	Mid-season	Late and harvest
Bean (green)	0.35	0.70	1.0	0.9
Bean (dry)	0.35	0.75	1.1	0.5
Cabbage	0.45	0.75	1.05	0.9
Carrot	0.45	0.75	1.05	0.9
Cotton	0.45	0.75	1.15	0.75
Cucumber	0.45	0.70	0.90	0.75
Eggplant	0.45	0.75	1.15	0.80
Groundnut	0.45	0.75	1.0	0.75
Lettuce	0.45	0.60	1.0	0.90
Maize (sweet)	0.40	0.80	1.15	1.0
Maize (grain)	0.40	0.75	1.15	0.70
Melon	0.45	0.75	1.0	0.75
Onion (green)	0.50	0.70	1.0	1.0
Onion (dry)	0.50	0.75	1.05	0.85
Pea (fresh)	0.45	0.80	1.15	1.05
Pepper	0.35	0.75	1.05	0.90
Potato	0.45	0.75	1.15	0.75
Spinach	0.45	0.60	1.0	0.90
Squash	0.45	0.70	0.90	0.75
Sorghum	0.35	0.75	1.10	0.65
Sugar beet	0.45	0.80	1.15	0.80
Sugar cane	0.45	0.85	1.15	0.65
Sunflower	0.35	0.75	1.15	0.55
Tomato	0.45	0.75	1.15	0.80

Crop	Young	Mature
Banana	0.50	1.10
Citrus	0.30	0.65
Apple, cherry, walnut	0.45	0.85
Almond, apricot, pear, peach, pecan, plum	0.40	0.75
Grape, palm tree	0.70	0.70
Kiwi	0.90	0.90
Olive	0.55	0.55
Alfalfa	0.35	1.1

Module - 6: Productive use of water [2]

6.1 Productive use of water for crop and livestock

With increasing population, change in diets and climate change, the challenge of shrinking freshwater resources will persist. By 2030 Ethiopia will be one of the countries in the world where physical water scarcity dominates. Obviously, with agriculture (combined crop and livestock) withdrawing the bulk of fresh water, targeting the practices of efficient use of fresh water would benefit agriculture and other sectors competing for the same water resources. This saving could be lower when we target single commodities (e.g. crop or livestock). In Ethiopia, livestock and crops are highly integrated (at least for major highland and mid-highland areas (Haileslassie et al., 2015). A significant proportion of crop residues are used for animal feed and manure inputs into the crop system, which enhances nutrient recycling. With expansion of irrigation into the pastoral system, there is increasingly high-level complementarity. In view of these arguments, in this module, we present efficient use of water in crop-livestock systems to show complementarities and system-level productive use of water at the landscape level. Rockström and Barron (2007) suggested that the challenges to improve water productivity (WP) of crops in rainfed systems are: i) to increase plant water uptake capacity; and ii) to increase plant water availability. However, in efforts to improve mixed-crop livestock systems WP, this is only one part of the equation. Integrating livestock into farming system water management strategies and following a water productive livestock management practice is important for maximizing WP (Peden et al., (2007); Descheemaeker et al., (2010); Haileslassie et al., (2009)). According to these authors: i) following a feed sourcing and feeding regime that can positively impact the livestock feed demand-supply side and that can regulate the contact between livestock and the environment ii) improving the WP of the feed and; iii) improving the productivity of livestock, are an important trajectory to improve the WP of a system. The following sections give details of these interventions.

6.1.1. Improving water productivity of crop and feed

a) **Increasing plant water availability:** increasing water availability is the first step in efficient use of water. Techniques for increasing plant water availability involves soil and water conservation and water harvesting and improved drainage (please see the previous section on in-situ and ex-situ water harvesting techniques). These practices improve plant water availability through reducing runoff, increasing infiltration, and distributing water across space and time (Alemayehu et al., 2008; Erkossa et al., 2020). Particularly, improved drainage creates opportunities for productive uses of excess water and reduces stress (due to waterlogged conditions and limitation on oxygen availability) and thus enhances vigorous plant growth and associated water uptake. Many Ethiopian smallholders have benefited from the Broad Bed Maker (BBM) technologies.

ILRI's and IWMI experience in semi-arid parts of Ethiopia show that integrating ex-situ water harvesting and productive livestock breeds provide farmers with a prolonged green fodder supply for their livestock (Figure 31). This involves, planting multiple-cut, high quality forage species. Over time this intervention has increased farmers' incomes and land-water productivity value manifold. Lessons can thus be learnt from previous efforts to enhance performance and adoption of rainwater harvesting technologies.

b) **Enhancing plant water uptake:** Plant water uptake capacity can, to a large extent, be improved through crop and soil management (Rockström and Barron, 2007). The target is to optimize depth and density of roots and development of canopy to increase the proportion of water flowing as productive transpiration. In this regard, for food crops, numerous

[2] *Extracted from Haileslassie et al., (20015).*

Figure 31: *Targeting and integrating interventions and engaging the community in managing landscapes (Photo credit: Amare Haileslassie).*

agronomic practices are feasible: improved tillage, crop rotations, crop choice, intercropping, weeds and pest management, plant breeding and genetic development (compare the integrated and optimization approach highlighted earlier). The point here is whether farmers in your farming systems have adopted such practices and how far these practices would be relevant to fodder crops and grazing lands in rainfed smallholder systems. There are several animal feed management technologies that are tested and proven to affect plant water uptake capacity. These include:

i) **Improving species diversity and composition:** Different plant species vary in their vertical and horizontal leaves and root structures. Plants on species diverse grazing lands and crop lands have different water depletion zones and thus less competition for water. Thus, grazing land management activities that involve frequency, seasonality, and selectivity of grazing affect species diversity and thereby plant water uptake capacity.

ii) **Grazing land management:** From three years of on-farm experiments, in the central highlands of Ethiopia (Ginchi, closer to Jeldu), Mewandra et al., (1997) showed that grazing intensity is key in affecting plant species composition and biomass. This same study further elaborated that medium grazed plots displayed a better plant composition and productivity. However, community-managed grazing land in Ethiopia does not seem to follow these principles, and mechanisms for dealing with this as common pool resources is lacking.

Other relevant questions include whether animal species diversity, which increases the probability of selective feeding on different plant species, could increase the overall grazing land and water productivity. A number of mechanisms have been proposed to explain observations of enhanced Dry Matter (DM) productivity under diverse plant species: diverse species could be complementary in resources uptake (e.g. water) either in space or in time. They also have a higher probability of containing more competitive and highly productive species and thus would enhance community biomass.

Desheemeaker et al., (2010) has indicated that grazing land enclosures significantly improved the biomass yield and therefore the livestock water productivity. But such practices may increase species richness to a certain level and enclosed grazing lands may experience decline in species diversity with age. This may question the long-term sustainability of such practices on system WP in general and Livestock water productivity (LWP) in particular.

iii) **Productive and more nutritive species:** If the target of increasing plant water uptake is to improve LWP, species selection (for diversity) must consider their productivity and feed values as criterion. In this regard Haileslassie et al. (2011) suggested that Metabolizable Energy (ME)[3] denser feed sourcing can save a significant volume of water.

In the past decades considerable efforts have been made to improve DM yields and quality of forage species of grazing lands in Ethiopia: by testing the adaptability of different species of pasture and fodder crops under varying environmental conditions. As a result, many useful species have been selected for the different altitudinal belts and production

[3] **Metabolizable Energy** *(ME) is the net* **energy** *remaining after fecal and urinary* **energy** *loss, and represents the* **energy** *available for growth or reproduction and for supporting metabolic processes such as work (locomotion) and respiration (thermoregulation, maintenance metabolism, HIF)*

systems in Ethiopia (Lulseged et al., 1985). In addition to the feed quality traits, these forage species could be multi-cut and the growing period is longer, and this creates opportunities for better water uptake and thus converts the evaporative green water losses to productive transpiration. Among the selected grass species, Rodes grass (Chloris gayana) Guinea grass (Panicum maximum) and Napier grass (Pennisetum purpureum) are highly productive, their annual DM yields ranging between 10 and 15 Mg ha-1. Moreover, in suitable areas, yields of oat-vetch mixtures are commonly more than 8 Mg ha-1 and that of fodder beet ranged from 15-20 Mg ha-1 (Lulseged et al., 1985). Although we do not have actual figures on DM yields of oat, in the teff system of Jeldu, we observed a poor crop performance. Focusing on those high yielding varieties can reduce competition for space with the food crops.

Among the selected forage legumes, spurred butterfly pea (Centrosema virginianum) and cowpeas (Vigna unguiculata) have been identified as potential species for cut and carry systems of feeding. These are good to plant on farm boundaries and also on physical conservation structures. Species recommended for under-sowing in perennial cash crops (e.g. coffee) or cereals (e.g. maize and sorghum) are Desmondium (Desmodium intortum, and Desmodium uncinatum) and Rhodes grass (Lazier, 1987).

In addition to the grasses and legumes, useful browse species including pigeon pea (Cajanus cajan), glricidia (Glricidia sepium) and, sesbania (Sesbainia susba) and leucena (Leucena leucocephala), have also been selected for the purpose of hedge planting (Lazier, 1987; Lulseged, et al., 1985). In one of the study areas, Descheemaker et al., (2010) illustrated an improvement in LWP as a result of on farm integration of shrubs like pigeon pea.

iv) **Soil fertility management:** This is an important intervention be it on crop land or grazing land. Soil fertility management includes physical, chemical and biological management. It is a requirement to have a vigorous plant growth and thus better water uptake. In many farming systems soil acidity, alkalinity and nutrient depletion are universal issue.

While fertilizer trials are common for crop land, its application and research on grazing land is rarely observed. A major argument is whether fertilizer on grazing land would pay off under current levels of animal productivity. There is promising results on effects of stages of harvesting and application of N fertilizer on DM yield of natural pasture in Fogera. Fertilizer application increased the DM yield by 36% and CP by 11.89%. In this respect, the relation between nutrient supply and water uptake are related. For example under low-nutrient conditions, pearl millet evapotranspiration efficiencies are roughly one-third of those obtained under higher nutrient input, suggesting that transpiration efficiency is also reduced by environmental stress including poor soil fertility and acidity.

Mewandra et al., (1997) suggested that application of manure improved the DM yield. But in many areas of Ethiopia, there is strong competition for manure (for household energy). However, as part of plant diversity enrichment, opportunity for silvo-pastoral interventions can be explored. Research evidence suggests that integration of legume and cereal fodder crops will have multiple effects: it improves the feed quality (e.g. CP) and also increases the DM yields through improved nutrient inputs and better water uptake.

6.1.2. Improving feeding and feed sourcing regimes

Improved feed management involves the following key aspects:

i) **Improving feed quality and practicing supplementary feeding:** For improved LWP, both quantity and quality of livestock feed is important. Such activities may involve selection, intercropping, chemical treatment and chopping of coarse residues. The higher the feed quality the less is the total dry matter demand by livestock (e.g. Haileslassie et al., 2011) and by implication this reduces the competition for space and water. For example, Haileslassie et al., (2011) illustrated that by improving feed quality (from 7 to 8.5MJ kg-1) as much 120 m-3 of water cow-1 yr -1 can be saved. Assuming 1.09 kg m-3 grain WP (e.g. in rice-based system (Descheemaeker et al., 2010)), feeding a poor-quality feed has an opportunity cost of 130 kg of grain. Descheemaeker et al., (2010) also reported, for the rice system in Fogera, improvement in LWP when crop residues were treated with urea.

Currently, grazing land feed quality is deteriorating because of overgrazing and flooding. Experiments show that through enclosure and managed grazing lands, DM productivity and species diversity can be improved. Except during the wet season of active growth, pasture plants are of low nutritive value. Production gains made during pasture growth are totally or partially lost during the dry season as feed supplies and quality declines. This will obviously affect the value of LWP. Thus, in addition to physical and chemical treatments, proper timing of harvesting and feed storage will contribute to maintaining the quality of feed in all study systems.

Normally Crude Protein (CP) content of less than 90 g/kg DM of diets will result in reduced rumen's microbial activity which leads to a reduction in degradation of cell walls and lowered feed intake. Most of the Ethiopian dry forages can only give about 62.09 g CP kg-1 DM of diet, which is far below the requirement. Thus, when dry forages are used without supplements, the microbial requirements are rarely met. However, there is a potential for supplementing low quality feeds by locally available protein-rich forage legumes (e.g. compare species diversification of grazing land and intercropping proposed) and agro-industrial by-products. This will improve the digestibility and associated DM intake and thus helps the animal to perform to its genetic potential and therewith increases LWP.

ii) **Limiting animal movement:** Limiting animal movement helps to reduce the amount of energy livestock require and thus the total DM intake. This in turn, reduces the water investment in livestock feed and thus increases LWP. In the rice system, Descheemaeker et al., (2010) and Haileslassie et al., (2010) reported ~ 12% of the Metabolizable Energy (ME) consumed by livestock are used for walking in search of feed and water. If we assume the average ME density of feed resources (teff 8, sorghum 7.4, chickpea, 6.6, maize 6.8 MJ kg-1 (Descheemaeker et al., 2010)), the energy needed for walking is equivalent to 1 kg DM. Taking a feed WP of 0.89kg m-3 and a livestock holding of 3.2 Tropical Livestock Units (TLU) per household into account, the water invested in walking would be 1230 m^3 per household per year or equivalent to an opportunity cost of 1340 kg of grain. The scenario can be even more water saving in the highland areas as the terrain is steeper and the climate is cooler and crop water productivity (CWP) could be higher, if the soil is not a limiting factor. Although the practice of cut and carry system helps to implement the concept of limiting animal movement, it has a tradeoff (e.g. labor requirement).

iii) **Quality drinking water supply:** Water is an important but often overlooked nutrient for livestock. In all study systems, livestock must move long distances to reach drinking water and in most cases the distribution is unsystematic and not synchronized with feed availability. In addition to the negative influences on animal productivity, such circumstances increase daily ME demand of the livestock and thus reduce LWP. For example, a cow weighing 250kg and walking 5 km on a 5% slope may need 3 MJ ME d 1 which is equivalent to 0.5 kg feed or 0.5m-3 of water per day. In terms of the current livestock holding per household, this is a significant volume which could be used for other livelihood or ecosystem services. In view of this, drinking water supplies (e.g. community ponds compare ex-situ water harvesting) could have multiple beneficial effects: increasing assimilation of ingested feed and reducing overall feed demand (Descheemaeker et al., 2011)).

In addition to the demand side, feed supply management through enhancing virtual water transfer and optimum feeding are important feed management strategies to improve LWP in landscapes.

[4] TLU is reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal. 1 TLU is equivalent to 250kg of liveweight of animal

Module 7: Socio-economic considerations

7.1. Governance of natural resources at landscape scale

Governance, from a natural resource perspective, refers to the norms, institutions and processes that determine how power and responsibilities over natural resources are exercised (Clement et al., 2011). It is about how men, women, indigenous people, and local communities participate in decision making and benefit from natural resources management (NRM). Rules and norms could be both formal and informal. Unwritten social norms, customs or traditions that shape thought and behavior is referred to as informal rules and norms. Written constitutions, laws, policies, rights, and regulations and formal rules and norms. These are normally enforced by official authorities.

In many instances, formal and informal rules and norms can be complementary, competing or overlapping. Under many circumstance development practitioners tend to prioritize formal institutions, viewing informal ones as separate and often detrimental to development outcomes. Whether they are relatively strong/weak or inclusive/discriminatory is likely to depend on context. In some cases, informal institutions undermine formal ones; in others they substitute for them. Informal social norms often shape the design and implementation of formal state institutions.

In the context to Ethiopia the major challenges related to governance of NRM at landscape scale are related to common property resources (CPR). Local CPR include grazing lands, threshing grounds, lands temporarily taken out of cultivation, inland fisheries, irrigation systems, woodlands, forests, tanks, ponds etc.

The need for greater levels of integration, coordination, and attention to multi-scalar (spatial and temporal) phenomena are among the characteristics of environmental and natural resource policy regimes that necessitate the development of new governance arrangements. Some of the principles that need to be considered in good governance of NRM involve:

- Refers to the validity of an organization's authority to govern.
- Transparency refers to: (i) the visibility of decision-making processes; (ii) the clarity with which the reasoning behind decisions is communicated; and (iii) the ready availability of relevant information about governance and performance in an organization.
- Accountability refers to the allocation and acceptance of responsibility for decisions and actions; and the demonstration of whether and how these responsibilities have been met.
- Inclusiveness refers to opportunities available for stakeholders to participate in and influence decision-making processes and actions.
- Fairness refers to (i) the respect and attention given to stakeholders' views; (ii) consistency and absence of personal bias in decision making; and (iii) the consideration given to distribution of costs and benefits of decisions.
- Integration refers to (i) the connection between, and coordination across, different governance levels; (ii) the connection between, and coordination across, organizations at the same level of governance; and (iii) the alignment of priorities, plans and activities across governance organizations.
- Capability refers to the systems, plans, resources, skills, leadership, knowledge and experiences that enable organizations, and the individuals who direct, manage and work for them, to effectively deliver on their responsibilities
- Adaptability refers to: (i) the incorporation of new knowledge and learning into decision-making and implementation; (ii) anticipation and management of threats, opportunities, and associated risks; and (iii) systematic reflection on individual, organizational and system performance

In the context to landscapes there are a great deal of CPRs that directly and indirectly relates to productive use of water. This involves for example water resources and irrigation schemes management. Since detail is provided in course number one on natural resources governance, this section will refer to irrigation scheme and water user association in the context to Ethiopia.

7.2. Governance – Irrigation Water User Association (IWUA) focused

Irrigation has increasingly become an important component of agricultural system in Ethiopian agricultural landscapes. Both formal and informal norms and institutions exist in this regard. In terms of formal institutions, the IWUA proclamation creates a specific legal basis for the establishment of

[5] This is extracted and shortened from Lempériere et al., (2014). More detail can be accessed on http://www.iwmi.cgiar.org

Irrigation Water Users' Associations (IWUAs) as a legal entity for operation and management of irrigation and drainage systems. The pre-existing legal framework in Ethiopia (i.e. cooperatives and associations proclamations) does not provide an appropriate legal basis for IWUA establishment.

The mandate of IWUAs is the provision of irrigation water to its members for agricultural purposes. It has a public interest nature because (1) IWUAs provide irrigation water to a large number of people – communities - and (2) they very often use public irrigation infrastructure, i.e. infrastructure built with public money and owned by the government.

Public law is the body of legal rules that regulates the conduct of state bodies including central and local government as well as bodies that undertake specific public functions such as public agencies, universities, hospitals, etc. based on specific laws. Therefore, **IWUAs are situated between the public and the private sector. They are self-governing, setting their own tariffs and making their own decisions as well as their operating rules. In accordance with their mandate, the tasks of IWUAs are strictly limited to management, operation and maintenance of an irrigation and drainage system and watershed management / protection**. IWUAs are not permitted to undertake any other activities such as the procurement of agricultural inputs or marketing of the commodities produced within the irrigation system they manage. Such activities are of a private nature. It is up to each farmer to decide how to procure inputs or market crops. This may be done individually or collectively through a marketing cooperative (or more than one cooperative, if needed). The supply of irrigation water is different: only one IWUA can operate within an individual irrigation system. Water is provided by the IWUA and no other body or agency.

IWUAs operate within a precisely delimited service area. It shall comprise a distinct hydraulic unit such as the command area of an irrigation system, part of the command area (secondary or tertiary unit) of a large irrigation scheme or part of a watershed. In most cases the service area will be the command area of the irrigation system that an IWUA operates and possibly the watershed upstream of the command area.

Compulsory IWUA membership: **Every person who, on the basis of a land right, uses land located within the service area of an IWUA is a member of the IWUA.** Compulsory membership is essential to ensure IWUA sustainability. With surface irrigation it is difficult in practice to prevent non-members from "free-riding" or benefiting from irrigation water (and even more so from drainage or watershed management services) without paying. Compulsory membership is a major difference between IWUAs and cooperatives or ordinary associations.

Membership is permanently linked to the land plots located within the Service Area of an IWUA. In other words, the membership obligation is not personal to the land holder or user as such; it is linked to the land which he/she uses.

IWUAs are non-profit organizations: **In many aspects, IWUAs are service providers; they provide irrigation water to their members who pay for this service** (irrigation service fee). For economic sustainability, it is essential and compulsory by law that each IWUA carries a financial surplus to build up a reserve fund to cover emergency repairs, replacement costs etc. To be clear on the non-profit nature of IWUAs, the Proclamation prohibits the distribution to members of any surplus income accruing to the IWUA; all surplus income must be paid into the reserve fund for uses limited to the irrigation and drainage systems.

7.3. Relations of IWUAs with other stakeholders

7.3.1. IWUAs supervising body

The State has the right (and the duty) to ensure that IWUAs operate lawfully and correctly in the public interest. To this end, the Proclamation requires each Regional State to establish an IWUA Supervising Body. The regional supervising bodies are tasked to be the entities in charge of irrigation. The supervising bodies will undertake two categories of activities: (1) extension activities and (2) legal and financial supervision. Certain extension activities may be delegated to other public or private entities or persons including:

- Providing training and awareness creation in connection with the establishment of IWUAs.
- Providing technical assistance and support to IWUAs including that related to water management, maintenance, financial management and gender issues.

7.3.2. Relation of IWUAs with the local government

Local governments (kebele or woreda administration) have an important role in supporting the establishment and operation of IWUAs. For instance, the local government can assist an IWUA in sanctioning wrongdoers, recovering outstanding payments of the irrigation service fee, or preventing unauthorized encroachment on the irrigation infrastructure. However, those actions are limited to support provided on the request of the Management Committee of an IWUA. It is very important that local government does not become intimately involved in the functioning of IWUAs and that it does not try to interfere or influence decision-making to protect the non-political nature of irrigation and drainage.

7.3.3. Transfer in use of irrigation infrastructures to IWUAs

In Ethiopia, like many other countries, the main justification of the transfer of irrigation infrastructure to users is to limit government budget expenditure and to institutionalize irrigation cost recovery by water users. It is also generally expected that transfer of irrigation management will contribute to improving the performance and increasing the sustainability of irrigation systems. However, international experience has shown a number of constraints to achieving the ideals; Ethiopia is not an exception. The transfer approach does not apply to traditional irrigation schemes entirely built and managed by farmers.

7.4. Roles and responsibilities of IWUAs

7.4.1. Tasks of IWUAs

The IWUA tasks are all related to operation and maintenance of the irrigation and drainage system located within its service area. IWUAs cannot engage in any other activity such as marketing products or the provision of agricultural inputs. Roles and related tasks of IWUAs can be sorted into three categories: (1) governance, (2) operation and maintenance, and (3) management:

1. Governance (or social management): This role relates to the role and responsibilities of the General Assembly: election of members of governing bodies, approval of budgets, action planning, and preparing annual reports, and adoption and amendment of regulations that govern day to day activities of an IWUA. Examples of operational rules include rules related to water distribution, maintenance of irrigation infrastructures, type and level of sanctions for violation of the rules, and defaults of payment of the irrigation service fee.
2. Operation and maintenance (O&M): This role include all activities that deal with planning, implementation and monitoring of water distribution and maintenance works, controlling soil erosion and soil fertility, and training IWUA members in irrigation techniques and/or water saving methods.
3. Management relates to the administration of the IWUA and the financial management.

Confusion between governance and management activities must be avoided. For instance, the IWUA budget is approved by the General Assembly (governance) and then implemented by the Management Committee (management). An extensive list of IWUA activities is found in the table below.

The main management tools of IWUAs to plan, implement and monitor their activities are (1) maintenance plans, (2) water distribution plan and (3) budgets. Other factors that need to be considered when establishing IWUAs include sources of revenue, operating principles, gender aspects and inclusion of women, as well as by-laws and internal regulations.

Table 4: *List of IWUAs activities*

Category	Activities
Governance (or social management)	1 Set up the objectives of the IWUA taking into account members needs and interests 2 Formulate strategies to reach the IWUA's. objectives 3 Set and/or modify internal regulations 4 Amend IWUA by-laws 5 Elect the members of the General Assembly and the governing bodies 6 Approve annual/seasonal action plan and corresponding budget 7 Approve annual/seasonal financial and activities report 8 Internal audit of the IWUA finance 9 Solve conflicts between the IWUA and it's members 10 Arbitrate conflicts among IWUA members 11 Approve contracts with external service providers 12 Approve change of the IWUA service area 13 Approve the reorganization or dissolution of the IWUA
Operation & maintenance	14 Regular inspections of irrigation infrastructures and equipment (i.e. pumps) 15 Prepare the annual/seasonal action plan for maintenance of infrastructures and equipments 16 Make sure that building material and spare parts for maintenance activities are available 17 Carry out routine, seasonal and emergency maintenance works 18 Monitor maintenance activities 19 If need be, monitor modernization or rehabilitation works and replacement of worn out equipment 20 Prepare an annual/seasonal plan for water distribution 21 Monitor the implementation of the annual/seasonal water distribution plan 22 Measure and monitor irrigation water use 23 Prepare annual/seasonal actctivities report 24 Adopt and use indicators for monitoring O&M 2S Identify and mitigate the risk of damage tt:o irrigation infrastructures and equipment 26 Identify and mitigate the risk of soil erosion, soil salinity 27 Train member in irrigation techniques
Management	28 Enforce IWUA by-laws and operational rules 29 Prepare annual/seasonal budget including the amount of the irrigation fee 30 Book keeping (accounting) 31 Make regular inventory and manage stocks of building materials, machinery and spare parts, fuel 32 Recover irrigation fees and apply sanction for non or late payment 33 Prepare annual/seasonal financial reports 34 Hire, supervise and pay IIWUA employees 3S Pass and monitor contracts with external service providers 36 Implement communication procedures within the IWUA 37 Keep IWUA archives 38 Any other activites assigned by the Genral Assembly or the Management Committee

8. Summary

Increasing population and climate change are putting pressure on scarce freshwater resources. Predictions show that many African countries will be under economic and physical water scarcity by 2030. Productive use of water and land is advocated to build a resilient landscape. Productive use of water is a process which combines different steps of adaptive management.

The different modules in the course are organized systematically and in logical order to enable cross-fertilization of ides across the modules. One of the major challenges for practitioners are the number of concepts, approaches and associated scientific jargon that have emerged over time. The conceptual understanding of agricultural landscapes, systems, and watersheds, which is the starting point for this manual, is an important foundation for the training process. It helps to link day-to-day activities of the trainees to science and brings the class to the same level of understanding and makes the teaching learning process simpler.

Approaches to water productive and resilient landscape are diverse and can be very complicated. In many cases, they are context specific and choosing approaches relevant to the context of the trainee and relevant for water productive landscapes is an important step in the training. Thus, this training manual focuses on approaches that complement each other where water is a production input (e.g. system/livelihood) and appears as an interface and medium of material flows between landscapes (rainfed, irrigation continuum) components (upstream, downstream, upper slope, mid-slope and valley bottom) and keep the landscape components connected. It could also be these approaches that facilitate landscape connectivity (e.g. value chain).

Planning and developing landscapes are a complex process because of the diversity of landscapes (both socially and bio-physically). This emerges from the heterogenous nature of the resource endowments and the livelihood expectation of the people in a landscape. Thus, an understanding of the landscape intensification pathway is required. In view of its heterogeneity there could be diverse pathways, for better off, medium, and poor farmers, or for upstream and downstream farmers who have different access to water. These development pathway clusters are closely linked to technology options. Governance is cross-cutting and influences (policy wise) the development pathways and technology options. This is where inclusiveness and transparency in decision making and benefits from collective water management are ensured.

A critical point to keep in mind is that this training manual and the course it supports cannot solve every problem related to landscape water productivity and resilience. It is just the beginning of the long and recurring journey. Its effectiveness depends not only on how we design and offer the training but also on follow-up (particularly coaching and mentoring of the practical applications), monitoring of impacts and use of documented evidence to shape future directions. This will enable evidence-based decision making and adaptive learning for sustainable management of landscapes.

References

Alemayehu, M., Peden, D., Taddese, G., Haileselassie A., Ayalneh, W. (2008). Livestock water productivity in relation to natural resource management in mixed crop-livestock production systems of the Blue Nile River Basin, Ethiopia. In: Humphreys, E., Bayot, R.S., van Brakel, M., Gichuki, F., Svendsen, M., White, D., Wester, P., Huber-Lee, A., Cook, S., Douthwaite, B., Hoanh, C.T., Johnson, N., Nguyen-Khoa, S., Vidal, A., MacIntyre, I., and MacIntyre, R. (Editors) 2008. Fighting Poverty through Sustainable Water Use: Volumes II. Proceedings of the CGIAR Challenge Program on Water and Food, 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10-14, 2008. The CGIAR Challenge Program on Water and Food, Colombo. 297pp. Balint, P.J., Stewart, R.E., Desai, A. & Walter, L.C., 2011. Wicked Environmental Problems: Managing Uncertainty and Conflict. Island Press, Washington D.C.

Anthony, Y 1997. Agroforestry for soil management. Cabi- Publishing New York, USA.

Aybike Ayfer Karadağ (2003) Advances in Landscape Architecture-Use of Watersheds Boundaries in the Landscape Planning, http://creativecommons.org/licenses/by/3.0.

Clement, F., Haileslassie, A., Ishaq, S., Blümmel, M., M. V. R Murty, Samad, M., Dey Sanjiib, D. and M. A. Khan (2011). Enhancing water productivity for poverty alleviation: role of capitals and institutions in the Ganga basin. Expl Agric 47. 133–151.

Descheemaeker, K., Haileslassie, A., Amede, T., Bossio, D. and Tarawali, T. (2010). Assessment of water productivity and entry points for improvement in mixed crop-livestock systems of the Ethiopian highlands. Advances in Animal Biosciences, 1, pp 491-492 doi:10.1017/S204047001000110X.

Descheemaeker, K., Bossio, D., Amede, T., Ayalneh, W., Haileslassie, A., Mapedza E., (2011). Analysis of gaps and possible interventions for improving water productivity in crop livestock systems of Ethiopia. Expl Agric volume 47: 21–38.

Eberhardt, U., Springgay, E., Gutierrez, V., Casallas-Ramirez, S. and Cohen, R. 2019. Advancing the forest and water nexus: A capacity development facilitation guide. Rome, FAO.

Erkossa, T., Haileslassie, A., & MacAlister, C. (2014). Enhancing farming system water productivity through alternative land use and water management in vertisol areas of Ethiopian Blue Nile Basin (Abay). Agricultural Water Management, 132, 120–128.

Erkossa, T., Geleti, D., Williams, T., Laekemariam, F., & Haileslassie, A. (2020). Restoration of grazing land to increase biomass production and improve soil properties in the Blue Nile basin: Effects of infiltration trenches and Chloris Gayana reseeding. Renewable Agriculture and Food Systems, 1-9. doi:10.1017/S1742170519000425.

Falkenmark, M., Wang-Erlandsson, L., & Rockström, J., 2020. Understanding of water resilience in the Anthropocene. Journal of Hydrology. X (2). https://doi.org/10.1016/j.hydroa.2018.100009.

Freeman, O.E., Duguma, L.A. & Minag, P.A., 2015. Operationalizing the integrated landscape approach in practice. Ecology and Society (20(1): 24.

Gebremedhin B.; Tesfamichael G.; Kristine M.; Walraevens K. 2016. Overview of micro-dam reservoirs (MDR) in Tigray (northern Ethiopia): Challenges and benefits. Journal of African Earth Sciences 123:210–222.

Granit, J, Liss Lymer, B., Olsen, S.B., Tengberg, A., Nõmmann, S., & Clausen, T.J., 2017: A conceptual framework for governing and managing key flows in a source-to-sea Continuum. Water Policy, 00 (2017) 1–19. doi: 10.2166/wp.2017.126.

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D. and Lesschen, J.P., (2005). Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, Ecosystems and Environment. 108 (1), 1-16.

Haileslassie, A and Craufurd, P (2012) Challenges in the dryland agricultural production systems of south Asia: research priorities and strategies. Annals of Arid Zone, 51 (3 & 4). pp. 1-8.

Haileslassie, Amare & Duncan, Alan & Peden, Don. (2015). Strategies to integrate livestock into agricultural rainwater management: an example from mixed crop livestock systems in the Blue Nile Basin. 10.13140/RG.2.1.2304.5841.

Haileslassie A.,Blümmel M.,Murthy M.V.R.,Samad M.,Clement F.,Anandan S.,Sreedhar N.A.Radha A.V.and Ishaq,S.(2011).Assessment of livestock feed and water nexus across mixed crop livestock system's intensification gradient: an example from the Indo-GanagaBasin.ExplAgric.47:113–132.

Haileslassie, A., Descheemaeker, K . Blummel, M., Craufurd, P., Ergano K., (2013a) Entry Points to Improve Livestock Water Productivity in

Selected Forage Based Livestock Systems. International Grass Land congress, Sydney 2013.

Haileslassie, A., Blümmel, M., Wani, S. P., Sahrawat, K. L., Pardhasaradhi, G., & Samireddypalle, A. (2013b). Extractable soil nutrient effects on feed quality traits of crop residues in the semiarid rainfed mixed crop–livestock farming systems of Southern India. Environment, Development and Sustainability, 15:723–741.

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T., Descheemaeker, D, (2009a) Livestock water productivity in mixed crop–livestock farming systems of the Blue Nile basin: Assessing variability and prospects for improvement. Agricultural system Volume 102, Issues 1-3, October 2009, Pages 33-40.

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T., Wagnew, A.Taddesse, G., (2009b). Livestock water productivity in the Blue Nile Basin: assessment of farm scale heterogeneity. The Range land Journal 31: 213-222.

Haileslassie, A and Craufurd, P and Thiagarajah, R and Kumar, S and Whitbread, A and Rathor, A and Blummel, M and Ericsson, P and Kakumanu, K (2016) Empirical evaluation of sustainability of divergent farms in the dryland farming systems of India. Ecological Indicators, 60. pp. 710-723. ISSN.

Intergovernmental Panel on Climate Change (2007) Fourth Assessment Report: Climate Change 2007, Glossary of Synthesis Report, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_ syr_appendix.pdf.

Lempériere, P.; Hagos, F.; Lefore, N.; Haileslassie, A.; Langan, S. 2014. Establishing and strengthening irrigation water users associations (IWUAs) in Ethiopia: a manual for trainers. Colombo, Sri Lanka: International Water Management Institute (IWMI). 76p. doi: 10.5337/2014.232.

Liao, C., Qui, J., Chen, B., Chen, D. et al. 2020. Advancing landscape sustainability science: theoretical foundation and synergies with innovations in methodology, design and application. Landscape Ecol (2020), 35: 1-9.

Lulseged G. Hiwot and Tadesse, A. (1985). Pasture Research and Development in Ethiopia. In: Kategile 1985 (ed.). Pasture Improvement Research in Eastern and Southern Africa. Proceedings of a Workshop held in Harare, Zimbabwe, 17 – 21 September 1984. Ottawa, Ont., IDRC, 1985. 508 p.

Molden, D.; Oweis, T. Y.; Steduto, P.; Kijne, J. W.; Hanjara, M. A.; Bindrban, P. S., 2007. Pathways for increasing agricultural water productivity. In: Water for food, water for life: A comprehensive assessment of water management in agriculture, Molden, D. (ed.). London: Earthscan. pp 280-310.

Muche, Habtamu & Abdela, Misba & Schmitter, Petra & Nakawuka, Prossie & Tilahun, Seifu & Steenhuis, Tammo & Langan, Simon (2017). Application of Deep tillage and Berken Maresha for hardpan sites to improve infiltration and crop productivity.

Mutyasira, V.; Hoag, D.; Pendell, D.; Manning, D.T.; Berhe, M. 2018. Assessing the relative sustainability of smallholder farming systems in Ethiopian highlands. Agric. Syst. 167: 83–91.

Mwendera, E. J., Mohamed Saleem M. A., and Woldu, Z., (1997). Vegetation response to cattle grazing in the Ethiopian highlands Agriculture, Ecosystems & Environment
Volume 64(1): 43-51.

Peden, D.; Tadesse, G.; Misra, A. (2007). Water and livestock for human development. In: Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London, UK: Earthscan, and Colombo, Sri Lanka: International Water Management Institute. Pp. 485-514.

Rockström, J. · Barron J. (2007). Water productivity in rain fed systems: overview of challenges and analysis of oprtunities in water scarcity prone savannahs. Irrig Sci 25:299–311.

Sayer, J.A., Margules, C., Boedhihartono, A.K., Dale, A., Sunderland, T., Supriatna, J. & Saryanthi, R. 2014. Landscape Approaches: what are the preconditions for success? Sustainability Science, 1862-4057.

Shalander, K., Craufurd, P., Haileslassie, P., Ramilan,T Rathore, A., Whitbread A., 2019. Farm typology analysis and technology assessment: An application in an arid region of South Asia. Land use policy, 8: 104-149.

Shem Kuyah, Ingrid Öborn, Mattias Jonsson, A Sigrun Dahlin, Edmundo Barrios, Catherine Muthuri, Anders Malmer, John Nyaga, Christine Magaju, Sara Namirembe, Ylva Nyberg & Fergus L Sinclair (2016) Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa, International Journal of Biodiversity Science, Ecosystem Services & Management, 12:4, 255-273, DOI: 10.1080/21513732.2016.1214178.

Shibeshi Assefa Birhanu Biazin Alemayehu Muluneh Fantaw Yimer Amare Haileslassie (2016) Rainwater harvesting for supplemental irrigation of onions in the southern dry lands of Ethiopia , Agricultural Water Management 178:325-334.

Rai M., Reeves T.G., Pandey S., Collette L. 2011. Save and Grow: A Policymaker's Guide to Sustainable Intensification of Smallholder Crop Production. Food and Agriculture Organization of the United Nations, Rome, (Report).

Smith A., Snapp S., Chikowo R., Thorne P., Bekunda M., Glover, J. 2017. Measuring sustainable intensification in smallholder agroecosystems: A review. Global Food Security 12: 127-138.

Tang, Q., Sean J. Bennett, Xu, Y., Li, Y., (2013) Agricultural practices and sustainable liveli-

hoods: Rural transformation within the Loess Plateau, China Applied Geography, 41: 15-23.
Tey, Yeong Sheng & Li, Elton & Bruwer, Johan & Abdullah, Amin & Cummins, Jay & Radam, Alias & Ismail, Mohd & Darham, Suryani. (2012). Refining the Definition of Sustainable Agriculture: An Inclusive Perspective from the Malaysian Vegetable Sector. Maejo International Journal of Science and Technology. 6. 379-396. 10.14456/mijst.2012.2.
The Montpellier Panel. Sustainable intensification: a new paradigm for African agriculture. (Agriculture for Impact, Imperial College, London, 2013).
United Nations International Strategy for Disaster Reduction (2005) Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters; Extract from the Final Report of the World Conference on Disaster Reduction, http://www.unisdr. org/ files/1037_hyogoframeworkforactionenglish.pdf.
Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Adaptability and Transformability in Social-Ecological Systems. Ecology and Society 9:5.
Yuan, Yongping. (2001). Modified SCS Curve Number Method for Evaluating Subsurface Drainage Flow. Transactions of the ASABE (American Society of Agricultural and Biological Engineers).
ZONNEVELD, I. S. Land ecology: an introduction to landscape ecology as a base for Land Evaluation, Land Management and Conservation. Amsterdam: SPB Academic Publishing, 1995. 199 p.

Annex 1 strategies to improve water productivity of crops and livestock

Strategy I: Increasing spatial and temporal plant water availability

Goal	Sub strategies and key practices	Impacts		Trade-offs and risks
		Livelihood capital	Ecosystem services	
Improving water productivity of crops and livestock feed	**Soil and water conservation:** integrated in-situ physical and biological soil conservation measures such as bunds of different types; fanya juu ; terracing; mulching; conservation tillage; grass strip along the contour; activities that enhance water infiltration (e.g. frequency, stocking density, timing of grazing) on grazing lands and fallow lands	■ Natural capital (e.g. soil conservation); ■ Social capital (e.g. health sediment free drinking water; less vulnerable to erratic rain); ■ Financial capital (e.g. benefit from increased biomass for feed; increased crop yield and less inorganic fertilizer cost	■ More productive ecosystem services; ■ Conserved water and land can be used for other ecosystem services like carbon sequestration; ■ Less competition between system elements for water (e.g. termite)	■ Downstream water flow reduced ■ Requires more labor input ■ Limits open access to CPR and thus the land less poor may be affected
	Water harvesting: includes ex-situ water harvesting (e.g. underground tanks, roof water harvesting; percolation pit; farm dam; tied ridge; community ponds; farm ponds; zai & planting pit system; large half moons; diversion weir; micro basins for tree).	■ Natural capital (e.g. soil conservation); ■ Social capital (e.g. health sediment free drinking water; less vulnerable to erratic rain and less time cost to collect drinking water for animal and human); ■ Financial capital (e.g. benefit from increased biomass for feed; increased crop yield and livestock productivity and less inorganic fertilizer cost)	■ Longer growing period and thus more carbon sequestration; ■ Improved regulatory services (e.g. runoff; sediment control)	■ Downstream water flow reduced; ■ More mosquito infestation; ■ Cost of construction and maintenance for farm pond
	Improved drainage: this could be on crop lands to use the drained water for second cropping, or supplementary irrigation (e.g. BBM; Cut off drains; graded fanya juu) and drainage of grazing land on valley bottom. The drained water can be used for drinking water supply for livestock.	■ Social capital (e.g. better health less malaria) ■ Financial capital (e.g. better productivity and production of crop ■ Natural capital (productive use of water)	May increase plant and diversity thus increase N fixation and pollination	■ Wet land drainage may affect water loving species

Strategy II: Increasing plant water uptake

Goal	Sub strategies and key practices	Impacts		Trade-offs and risks
		Livelihood capital	Ecosystem services	
Improving water productivity livestock feed	**Improving species diversity, composition:** management of frequency, seasonality and selectivity of grazing; over sawing; enclosure of degraded grazing lands (also on CPR) and intercropping n crop land	■ Natural capital (e.g. protecting degraded lands); ■ Financial capital (e.g. feed from rehabilitated lands)	■ Better pollination services; ■ Better plant cover and thus better protective and productive service	■ More labor cost; ■ Limits access to CPR and thus the land less poor may be affected ■ Incurs costs of inputs like seed
	Integrating productive and nutritive species: inter-cropping; under sawing of selected annual and perennial legumes on crop land, farm boundaries and fallow lands; control of invasive species (e.g. grazing lands)	■ Natural capital (e.g. increased nitrogen stock); ■ Financial capital (e.g. feed produced on farm boundaries	■ Nutrient cycling; ■ Better productive services	■ Reduces workability of field; ■ Some invasive species has cultural value and preferred by some livestock group; ■ More labor cost
	Soil fertility management: efficient use of manure; better inorganic fertilizer application on crop land; incorporating legume trees and crops as agro-silvo-pasture and silvo-pasture; liming for acidity	■ Natural capital (e.g. improved nutrient stock); ■ Financial capital (e.g. increased crop and feed yield)	■ Close nutrient cycling and thus less nutrient mining; ■ Better productive and protective services (e.g. erosion control)	■ Competition with household energy supply; ■ More fertilizer and lime costs; ■ Limits open grazing ; ■ If trees not managed tree competes for water

Strategy III: Improving livestock feed sourcing and feeding

Goal	Sub strategies and key practices	Impacts		Trade-offs and risks
		Livelihood capital	Ecosystem services	
Improved feed demand-supply management	**Improving feed quality and practicing supplementary feeding:** this includes selection of higher ME feed, inter-cropping, urea treatment, chopping of course residues; improved harvesting time, storage and supplementary feeding (e.g. concentrates if available, legumes incorporation in feed, green fodder from fodder bank...)	■ Natural capital (e.g. saves water thus land); ■ Financial capital (e.g. from improved animal productivity); ■ Social capital (e.g. better availability of milk and nutrition for the children; ■ Creates opportunity for feed trading	■ Feed supplemented with legumes has lower C:N ratio and thus allows organic matter decomposition and faster nutrient turn over; ■ Higher quality feed saves water which can be used for other ecosystem services (e.g. carbon sequestration)	■ Use of residues affects soil fertility management; ■ Poor farmers may not afford higher quality feed ; ■ Requires more labor input and cost of input
	Virtual water transfer to more water productive use: institutional support and creation of incentive mechanisms for local initiatives (e.g. land leasing, feed transfer from surplus to deficit system, feed marketing option.	■ Social capital (e.g. creates market linkage, poor farmers can keep livestock if there is access to feed market); ■ Finical capital (e.g. open opportunities to trade virtual water to generate income); ■ Natural capital (mitigate feed scarcity and thus mitigates over grazing	■ Can create opportunities for upstream and downstream community linkage; ■ Improved regional and systems water productivity	■ Leased lands could be poorly managed and thus may degrade in long term; ■ On leased land farmers can be hesitant to practice long term land and water management interventions
	Matching livestock activity and production level to available feed: can be a form of awareness creation on how to match cycle of animal production (activity, production level) with changing availability of sources of nutrient over time	■ Hunan capital (improved knowledge and skills)		■ Difficult to forecast feed sources from social linkage and CPR
	Limiting animal movement: through cut and carry; nearby drinking water supply	■ Natural capital (e.g. reduced compaction of soil	■ Tree planting on farm boundary and thus all associated ecosystem services benefits	■ More labor demanding

Strategy IV: Improving livestock management

Goal	Sub strategies and key practices	Impacts		Trade-offs and risks
		Livelihood capital	Ecosystem services	
Improving livestock productivity	**Selective and cross breeding:** This involves selection of productive local breeds; cross breeding local breeds with exotic breeds	■ Natural capital (better productive animal) ■ Financial capital (better return per unit of investment?)	Higher milk yielding requires less water per unit of milk and thus are water productive	■ Loss of indigenous breed ■ May affect farmers preferred traits (e.g. hump color etc…) ■ May los resistance to harsh environmental and disease (e.g. trypanosomes)
	Improving grass root level AI and veterinary service: policy incentives to involve more private services; Para-vet training for local people	■ Natural capital: (e.g. reduced animal mortality) ■ Human capital (improved knowledge and skills)	■ Reduced mortality saves water which can be used for ecosystem services (e.g. carbon sequestration)	■ Cost of the services
	Improving proportion of productive animal in the herd: destocking; matching traction need and oxen owned; multiple use of livestock; timely calling aged and sterile cows, timely heat detection mechanisms	■ Financial capital (e.g. higher return per animal) ■ Natural capital (less grazing area and less feed)	■ Higher LWP at herd scale	■ Affects herd diversity and risk mitigation strategies of farmers ■ Loss of cultural values of livestock
	Quality drinking water supply: water harvesting; and developing livestock watering points on irrigation canals;	■ Financial capital (e.g. higher milk yield) ■ Social capital (e.g. less time needed to trek livestock to watering points) ■ Natural capital (drinking points synchronized with feed availability and thus less over grazing)	■ Reduced erosion around water points	■ Higher cost of production and needs fewer and productive animal; ■ The poor may not have access to farm pond (land for run off?)