A framework for targeting and scaling-out interventions in agricultural systems

Working Paper No. 62

CGIAR Research Program on Climate Change,

Agriculture and Food Security (CCAFS)

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Correct citation:

Herrero M ., Notenbaert A., Thornton P., Pfeifer C., Silvestri S., Omolo A., Quiros C. 2014. A framework for targeting and scaling-out interventions in agricultural systems. CCAFS Working Paper no. 62. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org

Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

Published by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

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CCAFS Working Paper no. 62

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Abstract

There are real needs and opportunities for well-targeted research and development to improve the livelihoods of farmers while at the same time addressing natural resource constraints. The suitability and adoption of interventions depends on a variety of bio-physical and socio-economic factors. While their impacts -when adopted and out-scaled- are likely to be highly heterogeneous, not only spatially and temporally but also in terms of the stakeholders affected. In this document we provide generic guidelines for evaluating and prioritising potential interventions through an iterative process of mapping out recommendation domains and estimating impacts. As such, we hope to contribute to the inclusion of such important considerations when agricultural innovations are targeted and scaled out.

Keywords

Targeting; scaling out; impact assessment; priority setting; agricultural innovation

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Acknowledgements

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic partnership of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT).

The CCAFS Program is carried out with funding by the CGIAR Fund, the Danish International Development Agency (DANIDA), the Australian Government Overseas Aid Program (AusAid), Irish Aid, Environment Canada, Ministry of Foreign Affairs for the Netherlands, Swiss Agency for Development and Cooperation (SDC), Instituto de Investigação Científica Tropical (IICT), UK Aid, the Government of Russia and the European Union (EU). The Program is carried out with technical support from the International Fund for Agricultural Development (IFAD).

The work presented in this publication is a joint output of the EU-funded Animal Change project and the Targeting and Scaling-out project in the Nile Basin Development Challenge Program sponsored by the Challenge Program on Water and Food (CPWF). CPWF is funded by the UK Department For International Development (DFID), The European Commission (EC), The International Fund For Agricultural Development (IFAD), And the Swiss Agency For Development And Cooperation (SDC). The Animal Change project was funded under the FP7 program of the EU.

Contents

Introduction

The world's population is predicted to increase by 50% over the next years to reach 9 billion by 2050. On top of this, the impacts of climate change on global crop and livestock production may be substantial. The result of these and other drivers is that agricultural systems will face enormous pressures on the use of resources. As a consequence they will need to change to ensure the maintenance of livelihoods, food security and ecosystems services. An additional challenge lies in ensuring that the resource-poor, smallholder sector, which currently provides the majority of milk and meat in the tropics, is able to take advantage of opportunities as they arise to meet the increased demand for agricultural products. Systems are likely to have to intensify and promote strategies to increase resource use efficiency, but without compromising household food security, sustainable natural resource management, or rural livelihoods.

Investment in agriculture has increased in the last years, as the thrust of food security and environmental protection have become essential pillars of R4D strategies (Herrero et al., 2010; World Bank, 2007). Prudent use of limited resources is essential to ensure that the maximum gains from agricultural and NRM investments are obtained. This requires that resources are targeted in a rational way to the regions, sectors and production systems of the world that have the highest potential to achieve the triple wins of poverty reduction, environmental protection and food security. At the same time this requires a framework for targeting and scaling-out a variety of existing interventions for removing production constraints and protecting natural resources (mitigating climate change, promoting resource use efficiencies of water, soils, land and others). Farmers, service providers, policy makers and others supporting the agricultural sector, often have to make difficult choices between the different strategies to invest in and implement. All too often, short-term gains, which have an impact on household security in the near future, are chosen over options that can help to ensure the long-term sustainability of farming systems, such as prudent stewardship of soils and other natural resources.

There are real needs and opportunities for well-targeted research to improve the livelihoods of farmers by addressing resource constraints. Much work has been done on component or commodity research but the main problem remains that adoption of technology remains low for a large number of potentially beneficial practices. One reason for this is that research has tended to focus on just a small part of the total system. The "total picture" is complex, involving biophysical, economic, socio-cultural, institutional and environmental factors, all of which need to be considered in relation to the planned interventions and innovations. A mechanism that can facilitate a systematic, holistic assessment of the likely impact and consequences of potential interventions is one way of improving the selection and targeting of such options.

This document describes a generic framework for targeting, prioritising and scaling-out interventions in agricultural systems and outlines its implementation. We define interventions broadly as anything done to intervene or improve the agricultural system. This definition encompasses policy changes, governance (rule) changes, changes in management practices, adoption of new technologies or innovations.

Two underlying questions are addressed by this framework: which data are required for targeting and scaling out, and how can the data be integrated to assess different impacts of a range of interventions?

The work here builds on targeting work at ILRI over the last decade, notably on the work of Thornton et al (2002) (poverty mapping), Peden et al. (2006) (Water targeting), Thornton et al. (2006) (PRIMAS), Herrero et al. 2005 (Feed Resources Impact Assessment Framework), Freeman et al (2008) (FARA Recommendation domains), Notenbaert et al. (2009) (Production systems mapping), Notenbaert et al. (2011)(Dryland recommendation domains), and Robinson et al (2011) (Global livestock production systems). Some of these pieces involved significant stakeholder involvement to develop a set of coherent steps of analysis and selection of key indicators. During workshops, participants identified key aspects that they felt a comprehensive impact assessment framework should have, if it is to reflect the diversity of impacts that interventions of a different nature may have in different situations. These included attributes such as being able to deal with both simplified and more complex assessments, allowing users to engage with other stakeholders, and taking account of the different priorities of different target beneficiaries. Workshop participants also spent time on drawing up checklists that describe the key information required for carrying out targeting and impact assessment of agricultural interventions. These lists included information relating to targeting and identifying niches for specific practices, possible delivery mechanisms for adaptation and mitigation options, or water management options, market infrastructure, and service providers.

Bearing this in mind, the framework proposed here is designed for:

- Priority setting of intervention packages for increasing productivity and improving resource use-efficiency of farming systems.
- Priority setting of intervention packages and policies for adapting to, and mitigating climate change.
- Understanding the out-scaling potential of different packages of interventions (across landscapes, production systems and others)
- Improving the quantification of the impacts of different interventions on different dimensions of farming systems and agricultural landscapes
- A better understanding and quantification of the mitigation potential of different mitigation strategies in farming systems
- Including the assessment of trade-offs between different impact dimensions in the evaluation of intervention packages and mitigation strategies

1. The framework as a multistage process

Targeting and scaling-out are key components of the integrated ex-ante assessment process. The range of effects of change in agricultural systems, brought about by indigenous innovation, research and development, such as a new technology or a new policy, or by other drivers such as population growth or markets is quite broad. These effects include changes in production and productivity, income, food security, social welfare, and on environmental parameters such as emissions, water use, resource use efficiencies, etc (Peterson and Horton, 1993). They can be assessed at different scales, such as the farm, watershed or country, regionally or globally. The assessment of the effects need to be done within an integrated framework, that generally needs to take some account of the ecological, economic and social subsystems operating at each scale. In general, impact assessment studies can be divided into two types: those that deal with change that has already occurred (ex post), and change that has yet to occur (ex-ante). Most integrated assessments require a mixture of methods and analytical tools to generate appropriate information concerning the effects of the change being addressed. There is therefore a very considerable body of literature on ex ante impact assessment, ranging from strictly economic approaches (e.g.(Alston et al., 1995))) to other methods that try to blend "hard" and "soft" approaches (e.g. (Douthwaite et al., 2001)). A wide variety of tools and methods is reviewed in Thornton (2006) in relation to feed resources impact assessment and climate change, respectively.

The main objective of the framework developed here is to help people think beyond the animal or the plot scale, beyond productivity gains, beyond mean responses, and beyond a static analysis. The starting point for the development of this framework has been the general framework used for the ILRI priority setting work of 2000 (Randolph et al., 2001), shown in Figure 1. Research activities cover a fixed number of years to achieve planned milestones and generate the intended research output. Resources are required to achieve the objectives that can be measured in terms of scientist years and their ancillary fixed and operating costs such as support staff and laboratory infrastructure, and any large new capital investments. As a degree of uncertainty is inherent in science, we have to estimate the probability of achieving the planned outputs given the proposed level of resources within the defined time frame. This probability of success may be conditioned by many factors, such as for example necessary inputs not being available at the required time, or not being able to find appropriate scientific solutions to the research problem. Once the intended research output has been generated, a process of further adaptive research may be needed; alternatively, products may need to be developed that are customised to specific geographical areas, production systems, or sets of end-users. This may entail evaluation by various organisations, after which the product may then be disseminated to end-users through either formal or informal extension channels. Adoption of the end-product is often assumed to follow a sigmoid curve: adoption starts very slowly, gradually accelerating, then decelerating until the adoption ceiling is reached. In that study, impacts of research were considered in terms of their effects on productivity, the environment, and capacity building.

The general framework described in Randolph et al (2001)is useful, but there are several ways in which it could be extended. These include the following:

1. At a highly aggregated level, there is one overall adoption curve, but there may be several different ones at different scales, depending on the resolution of the niches (or recommendation domains) that we are interested in. It is this important to consider different spatial scales in assessing likely impacts: the animal or unit of land scale, in relation to production and productivity issues, for example; the farm scale, in relation to labour, food security and income issues, for instance; the community or regional scale, in relation to

communal grazing and water resources and social networks, for example; and the national and international scale, in relation to commodity prices and trade issues, for example.

2. Adoption is not a one-off process – people may dis-adopt, try the technology now and again, adjust the technology or switch to a new technology that was initially out of reach. It is thus important to consider the temporal scale in relation to adoption by potential beneficiaries.
3. Impact can be both positive and negative and the beneficiaries need to include indirect agents who may be affected both positively and negatively.

The framework described below tries to take a flexible approach in dealing with all these issues. In addition, we have to be realistic about the indirect but important impacts of production on prices, which will affect the people who actually benefit – society may be better off with lower consumer prices, but producers may actually be worse off because of lower profit margins (either increased input costs, or lower product prices, or both). Tools such as DREAM (Wood et al., 2000), Globiom (Havlik et al., 2009), IMPACT (Rosegrant et al., 2005), GTAP (Hertel et al., 1997), CAPRI (Mittenzwei et al., 2007) and others can quantify these types of shifts in supply and demand explicitly to different degrees. The framework developed here is expected to generate data that can be used to elicit the impacts of technology and policy through these modelling frameworks, or as a stand-alone 'discussion' tool of best options in specific farming systems or regions between stakeholders.

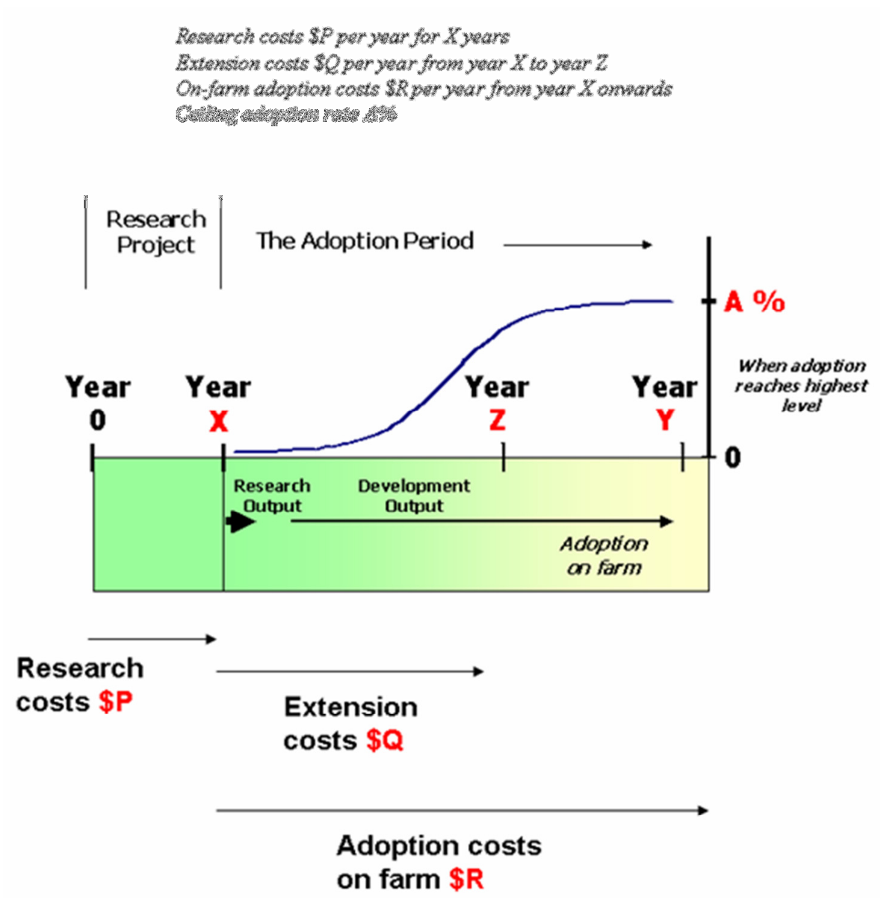
The proposed targeting and scaling-out framework contains several steps necessary for discerning how useful and how up-scalable specific practices might be at improving food security, NRM and livelihoods (and mitigating the impacts of climate change). The steps, in no specific order, are as follows:

4. What are the characteristics of the intervention that may affect its use and adoption in agricultural systems?
5. Identification of the recommendation domain for the products of research -- where are these likely to be applicable?
6. Who are the groups of people who are likely to be affected by the output of the technology/intervention?
7. What are the nature of the impacts, in terms of both the type of impact and their magnitude? What are the trade-offs at different temporal and spatial scales and between the different types of impacts?

These steps can be linked, by multiplying the impacts of the technology on the household (if that is the basic unit of analysis in the impact assessment) by the number of households in the recommendation domain. This process of extrapolation can be done in several ways, and often involves some sort of typology of beneficiaries (e.g., household types) related to factors such as wealth, access to resources, and production orientation, as these (and many other factors) may affect production and consumption choices of different households. Alternatively, the impacts of a particular mitigation practice on the reduction of GHG emissions per animal can be multiplied by the number of animals in a particular domain to quantify the mitigation potential of the practice. This can be done for alternative options, as the diagnosis of constraints and opportunities typically yields a set of alternative actions, practices or interventions. All of these could be assessed and prioritised in terms of impacts, coverage, mitigation potential, ease of implementation, costs and others. The assessment of the multiple impacts and careful investigation of their synergies and trade-offs can also feed into a revision of the original set of alternatives. Multiple iterations of characterisation, targeting and impact assessment then lead to well-informed prioritisation of actions.

We envisage that the framework would be used in a range of ways. With up-to-date information and knowledge on recommendation domains and production systems, it should help users to identify the likely impacts of the implementation of and potential bottlenecks in the uptake of specific technologies (e.g. improved feeds, water management, soil fertility practices). Second, the framework can be used as rapid screening and discussion tool, to screen sets of interventions in farming systems at the early stages of their development. For these first two uses, many of the data are likely to be qualitative in nature. A third use would be to use the framework to quickly evaluate the impacts of a wide range of interventions, then to identify sub-sets of promising specific interventions for evaluating using more detailed quantitative information, to estimate aggregated impacts in certain regions, or to link them to global and regional change models, for example.

Figure 1: A sigmoid adoption curve



Source: adapted from Randolph et al., 2001.

The various steps outlined above, start with the assumption that a potential intervention or set of interventions has been identified. An example set is shown in Table 1, taken from Thorne et al. (2002). This was an impact study that looked at potential interventions relating to the maize crop for food and feed use in East and southern Africa. Table 1 indicates the likely areas of impact for each intervention. For example, improving the management of green maize stover as an animal feed may have positive impacts on feed quality and feed quantity (through manipulating the timing when it is available to livestock with preservative treatment, for example), with resultant impacts on livestock productivity and GHG emissions (total and per unit of product). The nature of some of the potential impacts of particular interventions is not always clear, however. In relation to improved feeding systems that incorporate dry maize stover, for example (such as designing and using supplementation strategies year-round feed budgeting approaches), it is difficult to foresee what the resultant impacts on soil fertility are likely to be. In the Thorne et al(2002)study, these were estimated using simulation models of crop production, livestock production, and soil nutrient processes.

Table 1: Some potential interventions relating to the maize crop for food and feed use and their likely areas of impact

Intervention	Main areas of likely, beneficial impact				
	Feed quality	Feed quantity	Livestock productivity	GHG emissions	Soil fertility
Use of collected weeds of the maize crop for livestock feeding	√	√	√	√	
Improved management of green maize stover for feed use	√	√	√	√	
Improved feeding systems incorporating dry maize stover	√	√	√	√	
Chopping/soaking of dry maize stover	√		√		
Replacement fodder crops	√	√	√	√	√
Intercropping	√	√			√
Improved manure management strategies				√	√
Selection and/or breeding for improved digestibility of maize stover			√	√	

Source: Thorne et al., 2002.

1.1 Targeting interventions to their recommendation domain

It is crucial to understand that the characteristics and availability of the environmental and socioeconomic assets that agricultural production is dependent upon have important spatial and temporal dimensions. Some geographical areas are endowed with agro-ecological conditions suitable for rain-fed cropping, while in others agricultural activities require irrigation or are limited to grazing. Some regions have a well-developed road infrastructure, whilst others suffer from a lack of access to services and markets. Exposure to risk, institutional and policy environments and conventional livelihood strategies all vary over space and time. Hence it is very difficult to design intervention options that properly address all these different circumstances(Notenbaert et al., 2009). Agricultural research for development should, instead, aim at delivering institutional and technological as well as policy strategies that are well targeted to the heterogeneous landscapes and diverse biophysical and socioeconomic contexts the agricultural production is operating in(Kristjanson et al., 2005; Pender et al., 2006).

Recent years have seen considerable growth in the availability of spatial data that can be used to help answer targeting questions related to natural resource management, economic development and poverty alleviation. There have been many recent examples of prioritisation work on the basis of development domains. Development domains are defined as geographical units in which similar agricultural development problems or opportunities are likely to occur (Omamo et al., 2006). These regions are defined by various characteristics that may cut across national boundaries. These may be linked with agricultural potential, types of agricultural system, market access, and distribution of population, for example. Notable examples of these priority setting exercises can be found in Omamo et al.(2006), Freeman, et al(2008), , Notenbaert et al. The assumption is that agricultural strategies are likely to have the same relevance for areas falling in the same development domain. For example, the areas in the East and Central African region that are characterised by high agricultural potential, low market accessibility, and low population pressure, are seen as being a high strategic priority because of their size, suitability for different crops, and potential for growth. At the same time, these regions will require investment in infrastructure, security, and market access to be exploited (Dixon et al., 2001). Areas in the region that are characterised by high agricultural potential, good market access and high population densities are small in extent but contain relatively large proportions of the urban and rural population. The further development of these areas may well benefit from intensification and management-intensive techniques

A farming systems classification, i.e. a clustering of farms and farmers into farming systems for which similar development strategies and interventions would be appropriate, can form another spatial framework within which to organize research and the monitoring and evaluation of interventions. Dixon et al.(2001) for example, used a classification system to define commodity-specific regions and assess their potential for agricultural growth and poverty reduction and the relevance of five different strategy choices (intensification, expansion, increased farm size, increased off-farm income, and exit from agriculture). Random, clustered, or stratified sampling techniques can be used to identify sampling points or survey areas and case study sites selected within or across farming systems (Notenbaert et al., 2009). This kind of spatial sampling framework is a precondition for any out-scaling effort. System-specific baseline information can be collected, trends monitored, models parameterized for the different farming systems of interest and impacts assessed, both ex-ante and ex-post. This process is, for example, demonstrated in the ex-ante impact assessment of dual-purpose cowpea by Kristjanson et al. (2005).

Another response to the need for out-scaling has been the identification of “benchmark” sites for carrying out strategic research. Benchmark sites are identified to most closely characterize the broader agro-ecological zone of interest (DE PAUW, 2003)If the benchmark site can be taken as representative of a much broader environment, then the response may be assumed to apply throughout that environment (Thornton et al., 2006)The potential for out-scaling can be estimated using agro-ecological characterization and similarity analysis. However, this information needs to be complemented with household-level information to match interventions to specific types of producers, as significant heterogeneity exists in farming styles and objectives, resource endowments and farm types within a region (Solano et al., 2001)

In summary, the portability of technologies from one place to another requires knowledge about bio-physical and socioeconomic conditions that influence their suitability, adoption and success. By matching conditions favouring the successful implementation of a development strategy with a spatially referenced database, it is possible to delineate geographical areas where this specific strategy is likely to have a positive impact.

There are also characteristic influencing the adoption of a technology that are independent of the production system or socio-economic context to which they are targeted. Here, we want to highlight five important factors:

1. What are the costs to the farmer of implementing the technology, in terms of additional costs per hectare or per animal? Does the technology require capital or additional land, for example?

2. What is the level of managerial capacity and//or knowledge required for implementation of the technology?

3. What is the labour intensity of the new technology?

4. Which are the dissemination channels associated with the technology, and are these good, average or deficient?

5. What is the nature of the supporting environment for the technology -- favourable, moderate, or severely lacking?

These aspects can be described qualitatively for a rapid screening or in depth with quantitative information.

With respect to stakeholders, the implementation of the interventions may have both positive and negative effects. The categories of stakeholders that may be affected by an intervention may be the following:

- Farmers, stratified by wealth or production system (e.g., livestock/other, landless, crops, mixed, etc).

- Landless labourers.

- Urban and rural consumers.

- Other sector participants (including organisations).

- Other research processes/projects

It may be possible to link some of these groups to the development domains identified in step 1 above -- for example, databases may exist with the number of poor livestock keepers in specific systems, or numbers of households of particular types. It may thus be possible to quantify the sizes of some of the potential target groups.

In some situations, the impacts of a given technology adopted by an actor may be extended to other actors not adopting that specific technology. For example, a farmer increasing water infiltration by planning trees in the upland will have a positive impact on the farmer downstream, because more water will be available. It is therefore crucial to consider that impact from the adoption of a technology may affect different categories of actors, both adopters and non-adopters. It is therefore important to look at different incentives for each actor. Benefit sharing mechanism or payment for ecosystem services can be a way to set the incentive in such a way that each actor prefers to adopt the technology that contributes to the socially optimal outcome.

1.2 Identifying impacts

It is important to consider the temporal and spatial scales of the impacts of an intervention. For example, certain interventions may increase productivity in the short term, but in the long term they may reduce it as effect of the alteration of some key supporting/regulating ecosystem services. An example of this is the introduction of napier grass in the small-holder dairy systems. In the short run, improved diets for the dairy cows will increase productivity even. In the long term, loss of soil fertility could overturn this success. It is therefore important to combine such a technology with increased manure or fertiliser application. Similarly, negative impacts can be generated in a place as results of interventions that took place and generated benefits in another place (the upstream/downstream competition for water is a typical example of this).

Table 2 shows some of the impacts that may need to be considered, in relation to both spatial and temporal scale.

Another element that has to be consider in relation to the impacts of adopted interventions are the trade-offs. An increase in productivity, for example, does not necessarily result in a decrease in poverty levels, or increasing water productivity does not necessarily result in an increase in yield/productivity. The assessment requires scoring options along different dimensions, such as environmental impact, productivity, profitability, and social impact.

Trade-offs analysis typically yields multidimensional matrices that weight the interventions according to their impact along different dimensions and at differential temporal and spatial scales. The overall weight of the interventions will depend on the importance attached to each of the individual impacts.

Table 2 : Examples of impacts by time scale and spatial scale

	SPATIAL SCALE			
	Animal or Land Unit	**Farm**	**Community & Region**	**National & International**

TEMPORAL SCALE	**Short:** **Farm cycle**	• Productivity • Nutrient balances • Biodiversity • Profitability • GHG emissions • Water productivity	• Productivity • Income • Food availability • Biodiversity • GHG emissions	• Incomes (mean and distribution) • Food availability • Supply & demand shifts • Biodiversity	• Incomes • Food availability • Consumption patterns • Supply & demand shifts • Trade (export earnings, foreign exchange savings)
	Medium: **Early adopters,** **Information diffusion**	• Productivity • Biodiversity • GHG emissions	• Productivity • Income • Food availability		
	Long: **Technology adoption maturation**	• Productivity (sustained) • Biodiversity • GHG emissions	• Food security • Human health • Productivity	• Food security • Health • Incomes • Supply/demand shifts	

2. Implementing the framework

The successful implementation of the above framework ultimately depends on the availability of accurate information about each of the options being assessed. A wide variety of data sources can be consulted; a myriad of methods and approaches can be applied to generate useful information. This section describes a number of commonly applied methods for finding information for each of the framework components. It is meant to give pointers to the variety of methods that can be applied, but is in no way meant to be exhaustive.

2.1 Description of the interventions

Different technological, policy or institutional options are applicable in different contexts. The suitability of technologies and their adoption by farmers may be influenced by altitude, rainfall patterns, landscape position, soil type, access to input and product markets, crop-livestock interactions, the extent of community integration, the attitudes of local authorities, the presence of NGOs and other develop organizations – and many other factors (Feder and Umali, 1993).

The first step therefore includes the identification of the criteria – biophysical, socio-economic and institutional – that influence the suitability and adoption of a technology. The second step aims at mapping the places where these characteristics can be found, i.e. where the technology is likely to occur. We call these technology-specific niches or recommendation domains.

Different approaches can be followed to come up with the criteria that determine suitability and adoption. A first set of approaches starts from the assumption that these criteria are relatively well understood. The criteria are extracted from literature or elicited from experts. It is thereby important to go beyond the description of bio-physical suitability criteria and also describe the technology in terms of, for example, the cost of its implementation, the required capital investments, necessary managerial capacity and knowledge, the need for additional land or water, as well as the labour intensity.

Another set of approaches starts from known locations of presence and/or absence of success and uses these to investigate the factors influencing the occurrence and thereafter predicts where else they are likely to occur. Again a wide range of bio-physical, socio-economic and institutional factors needs to be included in the analysis to ensure that all important influential factors show up. In the following paragraphs, we describe a number of widely-used methods for identifying the combination of spatial data that can be used in the construction of recommendation domains. Table 3 summarizes advantages and disadvantages of each.

Table 3 : methods for identifying factors influencing suitability, adoption or success

Method	*Presence absence based*	*Principle*	*Advantage*	*Disadvantage*
1. Expert based multi criteria analysis	*No*	*each driver gets a weight*	*Simple*	*Weight varies with number of variable Implicit weights for continuous data*
2. Weight of evidence	*Yes*	*Bayesian data driven approach to identify success and failure of adoption*	*can handle socio-economic data in a data driven approach*	*Can handle only binary data*
3. Artificial neural network	*Yes*	*Learning algorithm*	*can handle socio-economic data in a data driven approach*	*Results heavily depend on the learning algorithm*
4. Bayesian network	*Yes*	*Bayesian learning algorithm*	*can handle socio-economic data in a data driven approach*	*Results heavily depend on the learning algorithm*
5. Small area estimation	*Yes*	*Regression on micro data defines weights*	*Allows to map socio-economic processes*	*Huge data need Weights based on models with low explanatory power*
6. Homologues	*Yes*	*Principal*	*Allows to identify*	*Includes only climate*

		component analysis	*sites with similar climate characteristics*	*data*
7. MaxEnt	*Yes*	*Statistical relationships and maximum entropy*	*Allows to identify sites with similar bio-physical characteristics*	*Includes only bio-physical data*

Expert based multi-criteria analysis is a relatively simple approach for which each driver identified in the characterisation of the technology is mapped (Quiros et al., 2009). Weights for aggregation can be equal for each criterion or based on expert knowledge. These approaches work very well with binary criteria, but lead to an implicit weighting for continuous data. Indeed, continuous data are often normalized between 0 and 1 before being aggregated. This normalization in fact already implicitly weights the importance of the driver. In addition, the weight given to one criterion will change as new criteria are added to the analysis.

The weight of evidence is a data-driven approach that makes use of the Bayesian rules in a log-linear form (Bonham-Carter, 1994). It can be applied where sufficient data are available to estimate the relative importance of evidential themes by statistical means. The evidential theme is a map indicating location of successful adoption of the technology. This approach can only be applied to binary data. A threshold needs to be defined for continuous data so that they can be transformed into binary maps.

An artificial neural network is a probabilistic network graph model, which consists of an interconnected group of artificial neurons (Lek and Guégan, 1999). It processes information using a learning algorithm that adjusts connection weights between the neurons. This can be applied to define the weights for aggregation of each criterion for mapping recommendation/suitability domains. It is a data driven approach but its outcome heavily depends on the chosen algorithm.

Bayesian network are based on the same principle that the artificial neural network, except that the learning algorithm makes use of a Bayesian simulation approach to define the weights (Jensen, 2007).

The small area estimation approach makes use of regression coefficients to aggregate different criteria (Davis, 2003). Regression coefficients can be defined based on a micro data survey that can be connected to spatially disaggregated census data. Small area estimation can be used to predict adoption rates for different technologies, and is an interesting approach to integrate socio-economic-institutional characteristics into recommendation/suitability domains. The drawback of this approach is that the regression models for adoption generally have a low explanatory power (R squared 0.1-0.3).

Homologue is software that finds locations with similar characteristics (Cock et al., 2008). It runs a principal component analysis on a whole range of climate data and identifies similar location based on the components score. The approach does not include data other than climate.

Finally, Maxent is software that identifies similar areas by maximizing entropy (Phillips et al., 2006). Given a set of successful adoption over some space, as well as a set of characteristics on this space, maxent estimates the target distribution by finding the distribution of maximum entropy (i.e.,that is closest to uniform). It is subject to the constraint that the expected value of each characteristic under this estimated distribution matches its empirical average.

2.2 Mapping recommendation domains

This step implies transforming the previously identified characteristics for a technology into variables for which spatial data exist and overlay these data. Often this implies the use of proxies, i.e. the use of a variable that can be measured (or is easy to measure) instead of one that cannot be measured (or is difficult to measure). For example, whereas it may be difficult to get data on the suitability of the soil and climate for a certain crop variety, it might make sense to use a general measure for the length of growing period. As in any GIS or modelling application, the key to success is the availability of accurate spatial input data. Spatial data collection is therefore one of the fundamental steps in this analysis. Data collection may be classified into primary and secondary methods. The primary methods of spatial data collection refer to deriving data directly from the field or from remotely sensed data sources. A variety of inter- and extrapolation techniques exist to estimate the variables at unobserved locations based on the values at observed locations. In secondary methods of data collection, data is normally derived from existing documents, such as maps, charts, graphs or by sharing already processed data.

Several researchers and institutions in recent years have put in a lot of effort and used new methods to map a variety of variables at global or continental scales. Some examples of readily available datasets are given in table 4. Despite increasing international efforts, the availability of timely, up-to-date and sufficiently spatially disaggregated data, especially in the socio-economic sector, remains patchy and incomplete. Major data gaps include for example measures of agricultural intensification and projections of market accessibility. Continued efforts from the ever growing number of data providers in the international arena and improved linkages and data sharing between them, is therefore needed to make this list grow further.

Clearly, these datasets show general trends in countries or regions, but little is known about the spatial heterogeneity when zooming down to resolutions that matter for practical applications. Assessments at more detailed scales therefore require higher resolution data.

Table 4 Examples of global and continental-level spatial data layers that can be used for targeting

Variable	Units	Source	Years	Spatial resolution
Area	km2	GIS calculations		0.05°
Human population	Numbers	CIESIN, GRUMP	2000	0.008333°
Human population	Numbers	Landscan	2005	0.008333°
Poor livestock keepers	Numbers	ILRI:, (Thornton et al., 2002)with 2009 revisions	2000, 2010	0.008333°
Poverty incidence (2$/day)	%	CSI	2000?	1km
Poverty incidence (1.25$ and 2$/day)	%	CSI	2000?	1km
Elevation	Masl	SRTM	2000	90m
Landcover	Classes	GLC2000 / GLOBCOVER2005	2000 / 2005	1km / 300m
Irrigation	% area equipped for irrigation	Siebert et al., 2007	2000	0.08333°
Land degradation	index	(Bai et al., 2008)	2000	1km
Market access	travel time to	(Nelson, 2008)	2008	0.05°

	major cities (hrs)			
Temperature(min, max, mean)	°C	Worldclim / Hijmans (2005)		0.008333°
LGP	Days	Jones and Thornton, revised frequently	different years	0.008333°
Rainfall CV	CV	Jones and Thornton, revised frequently (Jones and Thornton, 1997)	2000	0.008333°
Stunting	%	CIESIN	year of last survey	0.041667°
Underweight	%	CIESIN	year of last survey	0.041667°
Malaria	suitability	MARA/ARMA	2000	0.5°
Tsetse	suitability	FAO	2000	5.2 km
% cropping	%	Siebert et al.	2000	0.05°
Livestock (cattle, buffaloes, sheep, goats, small ruminants, pigs, poultry)	Numbers, Livestock Units, Density	Gridded livestock of the world - observed number of bovines (FAO, 2007)	2000, 2005	0.05°
Livestock (cattle, buffaloes, sheep, goats, small ruminants, pigs, poultry)	Numbers, Livestock Units, Density	SLP drivers study: Herrero et al. 2009	2030	0.05°
Crops (20 major crops)	Ha, MT, yield	You et al., 2007	2000	0.08333°
Crops (20 major crops)	Ha, MT, yield	SLP study: Herrero et al. 2009 based on IAASTD projections	2030	0.08333°
Cereal bran production	MT dry matter	SLP drivers study: Herrero et al. 2009	2000&2030	0.08333°
Cereal cakes production	MT dry matter	SLP drivers study: Herrero et al. 2009	2000&2030	0.08333°
Cereal Stover production	MT dry matter	SLP drivers study: Herrero et al. 2009	2000&2030	0.08333°
Methane production ruminants	Kg / TLU / yr	Herrero et al (in preparation)	2000&2030	0.08333°
Manure production ruminants	Kg /TLU / yr	Herrero et al (in preparation)	2000&2030	0.08333°
Grass consumption ruminants	Kg /TLU / yr	Herrero et al (in preparation)	2000&2030	0.08333°
Grain consumption ruminants and	Kg /TLU / yr	Herrero et al (in preparation)	2000&2030	0.08333°

pigs/chickens					
Stover consumption ruminants	Kg /TLU / yr		Herrero et al (in preparation)	2000&2030	0.08333°
Occasional feeds consumption	Kg /TLU / yr		Herrero et al (in preparation)	2000&2030	0.08333°
Livestock products (milk, meat)	t/yr		Herrero et al (in preparation)	2000&2030	0.08333°
Lakes and Wetlands	Type		GLWD	2000	shapes
Human development indicators	Varied		World Bank, WDR 2008	different years	country
World bank indicators	Numbers	Global	World bank	1960-2010	Country
Crop suitability (for 27 crop under rainfed conditions, land with cultivation potential)	index	Africa	GAEZ	2000	16km
Global land cover	Frequency	Global	European commission JRC	2000	0.5 º
Climate distribution	Climate types	Global	Koppen- Geiger climate classification	2007	0.5 º
Aridity	Index	Global	CGIAR- CSI	2009	1km
Failed Seasons	Frequency	Global	Harvest Choice	2008	0.1667
Drought risk areas	Index	Global	CHRR	2005	0.041667
Flood Risk	Index	Global	CHRR	2005	0.041667
Spread of Cyclones	Frequency	Global	CHRR	2005	0.041667
Pasture lands	Percentage	Global	Ramnkutty	2000	0.0833
Croplands	Percentage	Global	Ramakutty	2000	0.0833
Annual runoff	mm	Global	Annual Runoff (WWDRII)	1950-2000	0.5 º
Historic croplands	Percentage	Global	Ramankutty	1998	0.5
Forest Potential	Frequency	Global	IIASA	2000	0..07272
Potential natural vegetation	Frequency	Global	Ramanutty	1999	0.5
Organic carbon content for top soil	g/c/kg	Global	ISRIC- WISE	2006	0.08333
Soil fertility capability	Percentage	Global	Sanchez	2003	0.00833
Terrain constraints	Frequency	Global	FAO/FGGD IIASA	2007	0.08333
Bio-mass Carbon	Tones of	Global	Ruesch et al	2008	1km

	carbon bio-mass per hectare				
Agro- ecological suitability	Productivity	Global	GAEZ	2009	1km
WorldClim-Global Climate data	degCel, mm	World except Antarctica	WorldClim	1950 - 2000	1 km

Regional and continental data layers

Variable	**Units**	**Coverage**	**Source**	**Years**	**Spatial resolution**
Vulnerability	Index	Africa	Thornton et al., 2006	2000	16 km
Avian Influenza	Risk index	Africa	ILRI	2000	0.008333°
Crop suitability	index	Africa	GAEZ/Thornton et al.	2000	16km
Value of Production (beef, milk, lamb, pork, poultry, eggs / cattle, sheep, goat, poultry)	USD	Africa and South-Asia	ILRI: Notenbaert and Omolo 2008	2000	0.05°
Fire	Frequency	COMESA	NASA	2000	0.2 °
Conflicts	absence presence	COMESA	ILRI	2000	district
Internally displaced people	Number	COMESA	ILRI/IDMC	2000	district
Diarrhea	%	COMESA	DHS	2000	district
Acute respiratory infection	%	COMESA	DHS	2000	district
East Coast Fever	Incidence	COMESA	ECFexpert	2000	1:25 million
Locust risk	Risk index	COMESA	FAO	2000	0.05°
Roads, Rivers, Airports	Type	Africa	Land surveyors	2011	shapes

Single technologies or practices –even if applied in suitable environments- can't address the full suite of issues encountered in complex agricultural systems. In many cases different practices have to be combined or "mixed and matched" to identify overall farm- or landscape strategies. Some research programs aim at describing these packages of interventions, through e.g. participatory land-use planning. When defining recommendation domains for these packages, potential trade-offs and synergies at system or landscape scale will have to be taken into account.

2.3 The Affected Stakeholders

Once a recommendation domain has been identified and mapped it is possible to estimate the number of people living within the area where the intervention is applicable. A geographical information system (GIS) can be used to overlay population data with the recommendation domain and the total number of people can be calculated. If geo-referenced information about population structure (gender, age, household size, etc.) exists, also this type of information can be extracted.

The adoption of a new technology will affect several stakeholders across sectors at different levels. It is therefore important to understand who is gaining and who is losing from the new technology. These groups could be farmers, stratified by wealth production system or gender, landless people, urban and rural consumers, actors within the supply chain, or others such as NGOs, researchers or policy makers. There are several ways of identifying theses various groups, namely (i) expert knowledge, (ii) key informant interviews, (iii) focus group discussions, (iv) household/individual surveys.

Expert knowledge mainly relies on anthropologists and sociologists that have an understanding of the relationship and the power relationships between the different stakeholders and can therefore identify the relevant groups in the context of a given technology. Both, key informant interviews as well as focus groups allow the identification of the relationships and power relations as perceived by the stakeholders themselves. Key informant interviews are recommendable when important power differences between stakeholders are likely to inhibit free expression of the weaker stakeholders. Finally household surveys can allow the identification of particular groups of direct beneficiaries. Next to the descriptive analysis of the survey, it is possible to run adoption models that will show which household/individual characteristics explains the adoptions of a technology and therefore identifies the affected group in a quantitative way. This approach however does not allow to capture stakeholders other than the beneficiaries.

2.4 Assessing the Impacts

Impact can be described in terms of many different metrics: number of people affected, yield increases, economic returns, food security and income, environmental sustainability, social and cultural acceptability. Interventions should also have minimal externalities to be acceptable.

The assessments of, or choice between options, should be based on an evaluation of their impacts and how they contribute to the objectives that were envisioned. The next stage is to decide how to compare the contribution of different options to meet the objectives to be attained. This requires the selection of criteria to reflect performance in achieving the objectives. Each criterion must be measurable, in the sense that it must be possible to assess, at least in a qualitative sense, how well a particular option is expected to perform in relation to the criterion (Department for communities and local government, 2009). The consequences of implementation of various options can be evaluated by values of these criteria. Evaluating the impacts of an intervention thus involves estimating the values of these outcome variables. Often this is done by running simulation models. These models help us understand how the agricultural system might respond to the interventions and what the potential impacts are.

Different types of models exist, yielding different types of information. Often a distinction is made between mental models and mathematical models. A mental model is an explanation of someone's thought process about how something works in the real world. It is a representation of the surrounding world, the relationships between its various parts and a person's intuitive perception about specific actions and their consequences. These models typically provide qualitative assessments of impacts. Also mathematical and computer models are widely used for predicting the behaviour of a system under particular circumstances, when it is undesirable or impossible to experiment with the system itself. A mathematical model represents relations between decisions (x), external drivers (z) and consequences or outcomes. . The output of mathematical models is typically quantitative.

There is a variety of models available. Some typical examples include GIS, economic models, water-models, crop models, integrated models, financial analysis, cost-benefit analysis and trade-off analysis. The final selection ultimately depends on the criteria to be taken into consideration, the amount and nature of data available and the modellers' background, preference and experience. Reviews of some of these models can be found in van Wijk et al (2012).

The different outcome variables can then be taken into account by decision makers when comparing alternative solutions or setting priorities. Different stakeholders may, however, have fundamentally different value systems. Citizens of wealthy or developing nations, environmentalists, industrialists, and public officials may hold decidedly contrary views about what constitutes a desirable long-term future. Several methods exist for eliciting and ranking the outcome variables that decision makers and other interested communities want to use to assess the desirability of various alternative options. The importance of each of the outcome variables can be assessed by the analyst, the decision maker or they can be based on the views of the stakeholders. In some cases, this is done by panels of experts using techniques such as the Delphi method, outranking or the Analytical Hierarchy Process.

The criteria and their weights can feed into formal multi-criteria analysis (MCA) techniques to assign scores or rankings. The outcome from a MCA process is a prioritisation of alternative courses of action or interventions. Depending on the number of alternatives and criteria, the process can generate a vast amount of information. Graphical methods have been shown to be an effective way of presenting the results for different alternatives. Interactive computer packages are now available which enable the decision maker to view graphical outputs, as well as what happens if any of the key parameters or assumptions change.

The criteria and their importance can also be used to define objective functions, which can in turn be fed into an optimisation model. This optimization focuses on finding the optimal solution from a number of possible alternatives while meeting the given constraints.

3. Examples of application of the framework

Example 1: Diversifying, and modifying livestock feeding strategies as a climate change adaptation and mitigation strategy in Eastern Africa (adapted from Bryan et al., 2012)

This case study analyses the possible economic and GHG mitigation impacts derived from recently introduced alternative feeds for dairy cattle in the humid areas of East Africa.

The example targets smallholder dairy farmers that are reported to feed cattle with a mixture of rangeland grazing, crop residues and purchased grain concentrates. Diets of cattle have been constructed using the main feeds reported in a household survey in quantities devised to match reported diary production (Bryan et al. 2012). These, and alternative feeding strategies were then tested with livestock simulation models for their ability to increase milk production and reduce greenhouse gas emissions (methane)(Herrero et al., 2002).

The improved feeding practices tested the impacts of supplementing current livestock diets with *Desmodium intortum*, a high quality legume, supplied in quantity of 1 or 2 kg/day. This feed ingredient is also being promoted by several international agencies and projects (for example, the Bill & Melinda Gates Foundation East Africa Dairy Development Programme) as a vehicle for intensifying dairy production.

The diet was tested for methane emissions using the ruminant simulation model of Herrero, Fawcett, and Jessop (2002), to produce data on feed intake, productivity and methane emissions.

Table 5 summarises results of the simulation of the new diets, describing the technology and its impact.

Improved feeding practices are shown to lead to a triple win strategy that allows farmers to mitigate and adapt to climate change, meeting at the same time growing food demands and improving the livelihoods of poor smallholder producers. These practices have a fair GHG reduction potential coupled with a positive productivity response. The costs of implementation of the technology are low, hence they lead to increases in profitability.

However, the benefits and the trade-offs derived from the application are location specific and the proposed strategies provide more positive benefits in temperate and humid areas and may not be appropriate for drier areas.

This case study demonstrates that if simple practices and modest supplementation plans can be implemented, methane production in these regions could decline significantly. However, improved feeding practices generally will be profitable only if livestock owners have access to a market for dairy products as part of a sustainable intensification strategy: the greater the distance to the markets where outputs are sold the lower the probability of changing feeds since it reduces the access to inputs, but also to the information due to limited opportunities for exchange with other farmers. Non-farm income can provide an additional source of income to purchase feed and implement the adoption of this strategy.

It also illustrates that in order to reap the benefits of triple win strategies policymakers, researchers, and practitioners are required to move away from isolated approaches focused on either adaptation or mitigation or rural income generation toward a more holistic assessment of joint strategies as well as their trade-offs and synergies.

Extension/training will be fundamental since the adoption of the practice requires an increased knowledge and management, as farmers have not been exposed to this feed resource in the past.

Table 5 : practice description

Practice	Diversify/change/supplement livestock feeds ▪ Baseline feeding strategy: rangeland grazing, crop residues (maize stover), and roadside weeds ▪ Improved livestock feed: +1 kg/day of Desmodium instead of maize stover +2 kg/day of Desmodium instead of maize stover
Bio-physical purpose	▪ Improved livestock feeding
Socio-economic purpose	▪ Mitigate climate change: reduced methane emissions ▪ Adapt to climate change: increase the productivity of diary cattle, and increase net profits from the sale of milk ▪ Meet growing food demands and improve the livelihoods of poor smallholder producers

Description of the technology	
Targeted system	▪ Smallholder dairy systems
Geographical coverage	▪ Humid and temperate areas of East Africa
Nature of the supporting environment: environmental constraints	▪ Not suitable in the arid sites, where livestock are grazed and feed is usually not purchased.
Nature of the supporting environment: socio-economic constraints	▪ Extension/trainings to promote adoption for farmers that have not been exposed to this feed resource in the past ▪ Distance from the markets, where improved feeds can be purchased, could influence adoption : ▪ Public provision of improved feeds could facilitate adoption ▪ Access to information
	▪
Level of managerial capacity	▪ Medium
Level of external inputs required for implementation of the technology	▪ High availability of Desmodium seeds
The Affected	
Who can be affected by the output of the technology	▪ Market oriented dairy farmers ▪ Hired labourers ▪ Milk consumers (through potential increased milk production and milk price reduction) ▪ Milk marketers
Impact	
Productivity response	▪ Baseline production of milk: 548 Kg/yr Implemented milk production: +1 kg/day of Desmodium = +21% Implemented milk production: +2 kg/day of Desmodium = +36%
GHG reduction potential	▪ Baseline feeding strategy: methane production: 780 (kg CO_2 eq/lactation) methane produced per liter of milk: 1.42 (kg CO_2 eq/L) ▪ Improved feeding strategy (+1 Kg/day Desmodium):

	methane production: -3 % (per year, % difference) methane produced per liter of milk: -20% (per liter of milk, % difference) ▪ Improved feeding strategy (+2 Kg/day Desmodium): methane production: 0 % (per year, % difference) methane produced per liter of milk: -26% (per liter of milk, % difference)
Cost of carbon emissions	▪ Baseline feeding strategy cost of CO_2 equivalent emissions: 7.77 (US$) Improved livestock feed: +1 kg/day of Desmodium = 7.52 (US$) Improved livestock feed: +2 kg/day of Desmodium = 7.85 (US$)
Costs of implementing technology	▪ Baseline feeding strategy cost of feed: 112 US$/yr Improved feeding strategy (+1 Kg/day Desmodium) = 38 US$/yr Improved feeding strategy (+2 Kg/day Desmodium) = 68 US$/yr ▪ Baseline feeding strategy cost of labour: 18.8 US$/yr Improved feeding strategy (+1 Kg/day Desmodium) = 22.7 US$/yr Improved feeding strategy (+2 Kg/day Desmodium) = 25.5 US$/yr
Profitability	▪ Baseline feeding strategy net revenue (US$/yr): 62.2 US$/yr Improved feeding strategy (+1 Kg/day Desmodium) = 172.3 US$/yr Improved feeding strategy (+2 Kg/day Desmodium) = 169.2 US$/yr ▪ Baseline feeding strategy net revenue per liter of milk (US$/yr): 0.11 US$/yr Improved feeding strategy (+1 Kg/day Desmodium) = 0.26 US$/yr Improved feeding strategy (+2 Kg/day Desmodium) = 0.23 US$/yr

Note: MJ = megajoules; ME = metabolizable energy; DM = dry matter.

Note: We assumed carbon price of US$10 per ton of CO_2 equivalent.

Source: Bryan et al., (2012)

Example 2: Rainwater management strategies for the Blue Nile in the Ethiopian highlands (adapted from(Pfeifer, 2011))

Study area and problem description

The Blue Nile in the Ethiopian Highlands belongs to the humid tropics. About 98% of agriculture is rain-fed in a mixed crop-livestock production system. Annual rainfall ranges between 800-2500 mm, which is unevenly distributed across the year. Whereas farmers are challenged by flooding and water logging during the rainy season, dry spells during the dry season are the major reason for crop failure. As such, the lack of water management explains to a large extent the prevailing poverty and food insecurity.

Many rainwater management technologies, such as terraces, bunds, water harvesting or reforestation have been implemented in Ethiopia with relatively low success. This is mainly because these technologies were implemented in a top-down approach and often did not suit, nor the bio-physical, nor the socio-economic or institutional contexts. There is therefore a need to understand what works where.

In addition, technologies need to be combined into “packages”, at farm scale in order to capture the complexity of the mixed crop-livestock system as well as at landscape scale in order to capture for example the potential benefits occurring in the valley bottom thanks to technologies applied in other locations of the landscape.

Characterization of technologies

The set of rainwater management technologies applicable in the Blue Nile as well as the factors of success and failure are relatively well documented. A broad literature review followed by a stakeholder workshop allowed the development of a large database of technologies that contains for each technology the purposes as well as the conditions for successful adoption. Whereas bio-physical purposes and conditions of success are mostly described quantitatively, the descriptions of socio-economic and institutional conditions are more qualitative and studies sometimes contradict themselves.

A framework to combine technologies into a "package" has been developed. At farm scale, a package is a set of technologies that have to be implemented together; a well for example needs to be combined with a water lifting system. At landscape scale the framework divides the landscape into 3 zones, namely the highland, midland and lowland as well as 3 land uses, crop land, grassland and heavily degraded land. In each zone-land-use combination a certain objective should be followed. Table 6 shows these objectives as well as examples of technologies applicable in the Blue Nile basin.

Table 6 : objective of a technology on different land-uses in different landscape zones

	Main objective(examples)		
Zone	Cropland	Grassland	heavily degraded land
Uplands	Increase infiltration (All forms of forestry)	Increase the quantity and quality fodder for livestock (over-sawing, area exclosure)	Rehabilitate degraded land (half moon, forestry)
Midlands	Increase soil and water conservation (bunds, terraces)		
Lowlands	More efficient use of surface or shallow water (Wells, rivers)		
Independent	Increase water in the dry season (Ex-situ water harvesting)		

A landscape scale technology package is a combination of farm-scale packages that cover at least the three zones.

Mapping technologies

As an illustration, one "package" consisting of three technologies suggested by the stakeholders has been selected, namely orchard, modelled here with apple and mango trees for the uplands, terraces modelled here with bench terraces and hillside terraces for the midlands and river diversion for the lowlands. The database contains for each of these technologies success conditions that need to be transformed into "mappable" proxies. Table 7 shows the selected proxies, as well as the suitable range for biophysical conditions.

Table 7 : success criteria for each technology

Technology		Biophysical criteria	Expected socio-economic and institutional criteria (to be tested and integrated in adoption maps)
Upland : orchards	Apple tree	Minimum temperature below 10c Luvisol, nitisol, leptosol Sub-humid zone	Distance to market Land holding size
	Mango trees	Nitisol* Sub-humid zone	Distance to market Land holding size

Midland : terraces	Bench terracing	Semi-arid and sub-humid zones* soils drainage ≠ poor Slope between 12-58%	Household size Hired labor Access to advice Land fragmentation Agricultural dependency Rented land
	Hillside terracing	Arid and semi-arid slope 10- 50%	household size Land holding size Hired labor Access to advice Land fragmentation Agricultural dependency Rented land
Lowland	River diversion	2.5km around perennial river soil texture = fine	Access to capital Household size Access to advise Access to market

Binary maps have been created for each bio-physical suitability condition. Bio-physical conditions for each technology can then be multiplied resulting in an equal weighting of each condition. Socio-economic and institutional characteristics are not yet well understood and do not have a clear suitability range nor is there is a rational to weight different characteristics. Therefore, we perform a probit analysis explaining the adoption of a technology, including the variables inTable 7. In accordance to the small area estimation technique, the coefficients of the regression are then applied to spatially referenced census data (see appendix 3 for a detailed description). The result is an adoption map that suggests locations in which conditions are more favourable for adoption of the technology and therefore represents a “willingness of adoption”. Finally, the different suitability maps can be overlaid with a “landscape map to identify those landscapes that are suitable for and are likely to exhibit adoption of the rainwater management package.

Figure 2shows the bio-physical suitability maps for individual technologies, namely apple, mango, bench terraces, hillside terraces and river diversion. These technologies have been aggregated at landscape scale, using the FAO watershed delineation. The rule applied to identify suitability of the package “orchard-terraces-river diversion” is based on biophysical suitability of the single technologies. The following rule has been applied to identify suitable watersheds: more than 10 % of the area was suitable for orchards, apple or mango, more than 10% of the area was suitable for terraces, bench or hillside terraces and more than 2% of the area is suitable for river diversion.

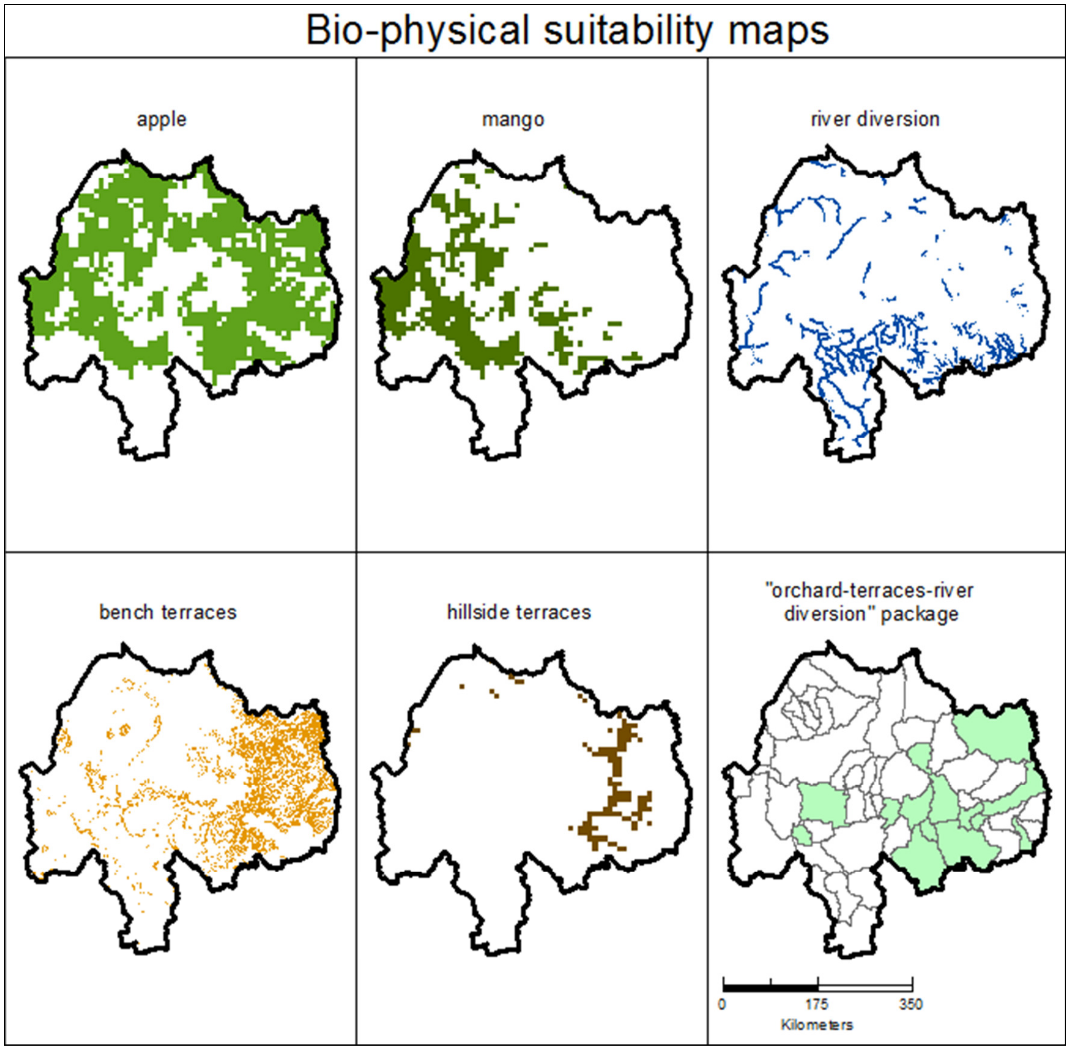


Figure 2 : bio-physical suitability for orchards, namely apple and mango, for terraces, namely bench and hillside terraces, river diversion as well as their aggregation into landscape scale package.

Figure 3 shows the bio-physical suitability maps that have been overlaid with the willingness of adoption maps (in appendix). The more intensive the color the more smallholders on these locations are likely to adopt the technology.

In order to aggregate the different willingness of adoption at landscape scale, the minimum average willingness of adoption on suitable locations is selected. This approach indicates where the package is most likely to succeed, but does not take into account the area that can potentially be under a given technology. Therefore one can combine the bio-physical package map with the minimum average willingness of adoption, in order to identify adoption in suitable watershed (area suitable for orchards >10%, area suitable for terraces >10% and area suitable for river diversion >2%)

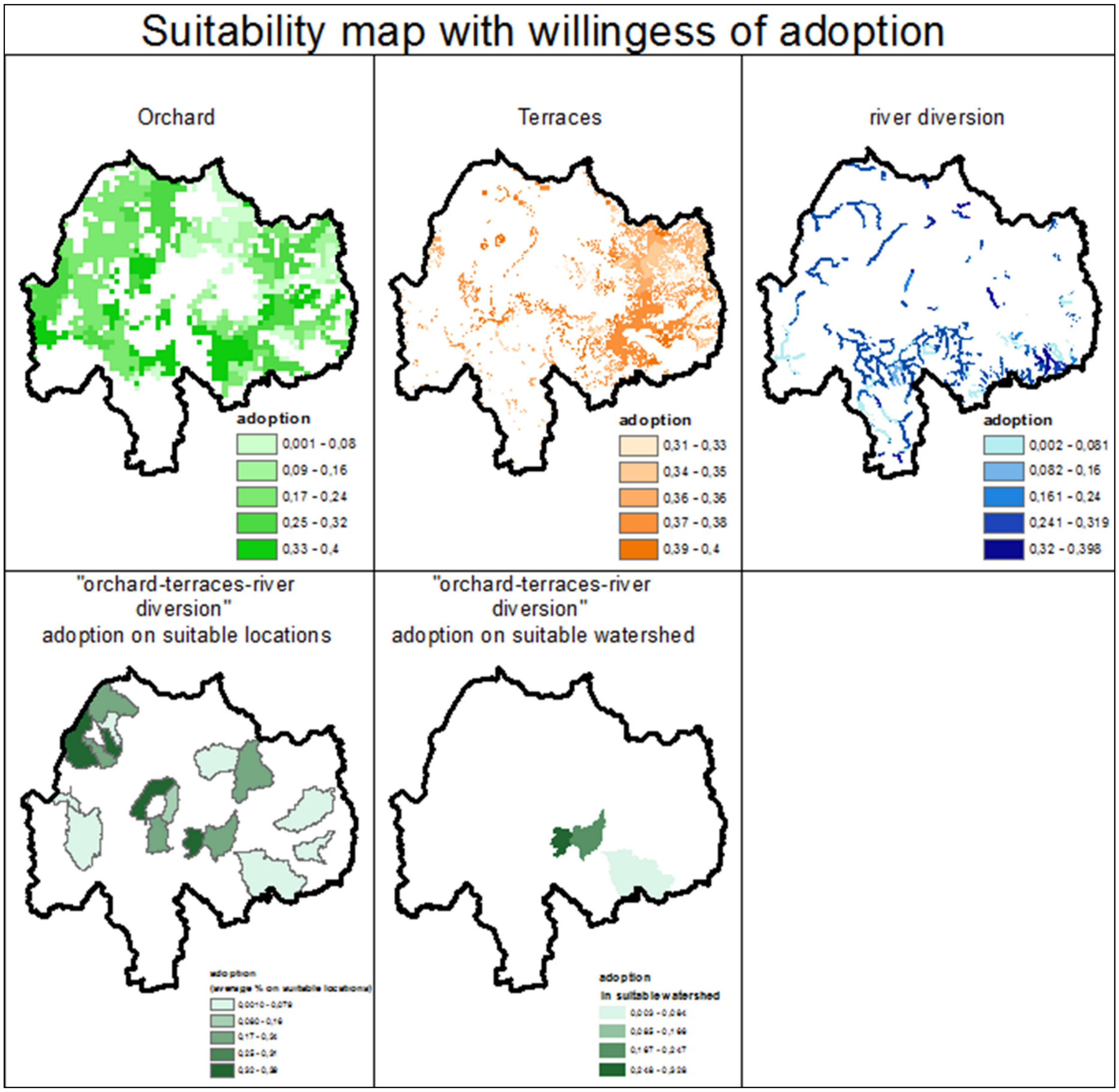


Figure 3 : suitability map including the wilingess of adoption for each technology, namely orchard, terraces and river diversion as well as its aggregation into a “landscape pacakage”.

The Affected

Rainwater management practices are likely to have up-stream down-stream effects. Therefore, it makes sense to stratify the affected by their locations along the slope. The upland smallholder helps increasing infiltration, and the midlands smallholder contributes to the conservation of water and soil. By doing so they improve the water availability of the lowland smallholder who has more water available and can potentially add a second cropping season thanks to small scale irrigation. As such, a smallholder in the up and midland has little incentive to adopt any technology which mainly affects the lowland farmer. Therefore, each technology should be profitable at farm scale: orchards result in cash revenue from the sale of fruits, multipurpose tree increase fodder for livestock in the dry season, terraces result in higher crop productivity and small scale irrigation results in cash for irrigated high value crops. When the farm-scale incentive is not sufficient to motivate up and midland farmers, benefit sharing mechanisms should be put in place. Introducing benefit sharing mechanisms should be a bottom-up process that involves all the stakeholders in order to ensure acceptability and equity.

Also, smallholders in downstream landscapes can be affected by decisions taken in the upstream landscape. The only way to assess to what extend adoption of rainwater management strategies affect smallholders in downstream landscape is to assess the hydrological impact. This is discussed in the following section. If impact on hydrology is negative for the downstream landscape and countries, water becomes a political issue that involves Northern Sudan and Egypt.

Impacts

Impact of the adoption of a rainwater management package on livelihood can be assessed as changes on livelihood assets. Table 8shows the hypothesized impacts of the "orchard-terracing-diversion package" on livelihood asset indicators at different scales. In order to identify potential winners and losers at farm scale, farms have been stratified into their location within the landscape.

In terms of natural capital the rainwater management package is expected to increase soil water moisture, reduce erosion and sedimentations at all scales. Blue water will increase mainly in the bottom of the landscape. Its impact on the whole basin is uncertain; if more water is retained in one landscape there might be less water in the downstream landscape. A combination of SWAT and WEAP modelling aims at testing these hypotheses.

Impact on crop production depends on the location within the landscape. In the uplands crop production will be reduced as trees will be planted on cropland. In the midlands crop production will increase mainly through productivity gains achieved by higher soil moisture. In the lowland, crop production will increase through small scale irrigation schemes allowing additional cropping seasons for high value cash crops. Overall at landscape and basin scale, crop production is likely to increase. These hypotheses will be tested with AquaCrop, a model that simulates impact of more soil moisture on different type of crops.

In terms of agro-forestry, timber will increase mainly in the uplands where trees are planted, though a relatively long time scale needs to be considered until timber gets profitable.

Impact on livestock for the given package is uncertain, mainly because the chosen package does not have a direct impact on livestock (such as improved breeds, or grassland management). However, biomass production is likely to increase, thanks to trees in the uplands as well as improved crop productivity in the mid and lowlands, implying that there is more fodder available for livestock, resulting in higher livestock productivity or more livestock. A livestock water productivity framework will allow the assessment of these indirect impacts of increased biomass on livestock.

Table 8 Hypothesized impact on livelihood assets at different scales and model available to test them

Livelihood asset	Indicator	Farm upland	Farm midland	Farm lowland	Land-scape	Basin	Model
Natural capital	Erosion	-	-	-	-	-	SWAT
	Sedimentation	n/a	n/a	-	-	-	SWAT
	Soil moisture (green water)	+	+	+	+	+	SWAT
	Blue water	0	0	+	+	?	WEAP
Financial capital	Crop	-	+	+	+	+	AquaCrop
	Livestock	?	?	?	?	?	LWP
	Timber	+	+	0	+	+	-
	Income	?	+	+	?	?	Ecosaut
	Poverty	?	-	-	?	?	-

Physical capital	Infrastructure	0	+	+	+	+	-
Human capital	Food security (health)	?	+	+	?	?	-
Social capital		?	?	?	?	?	?
Expected impacts: + increase, - decrease, 0 unchanged, ? uncertain, n/a not applicable							

Further investigation is necessary to elucidate potential saturation of markets and decrease in prices due to wide-spread adoption. But assuming that the market for agricultural products is not saturated, income as well as food security are likely to increase on the lowlands, thanks to the additional high value cash crops. In the midland, higher crop productivity will lead to more income if surpluses are sold or to better food security. Financial impact for the upland is uncertain, as crop production decreases. Income is likely to increase in the long term when fruits can be harvested, but in the short term the upland smallholder is likely to incur losses. Ecosaut is an economic optimization program that optimizes income given a set of constraints, mainly bio-physical constraints as well as production inputs. This approach will allow to test if there are options for farms in each zone to find a viable outcome.

Terraces and diversions are part of the infrastructure which increases when these technologies are implemented. On contrary, the impact on social capital is uncertain. Social capital might improve if smallholders are ready to corporate and create water management cooperatives at landscape scale, but social capital could also deteriorate when cooperation is not possible and tension between smallholder increases.

Impacts on livelihoods have multiple dimensions and often lead to trade-offs. Different stakeholders might have different objectives and weight the different impacts differently. For example, the upland farmer might not adopt orchards because he faces short term losses from fruit trees, whereas the community could gain in overall water productivity. Therefore, it is important to implement these packages with bottom-up approaches with communities. In these processes, smallholders and other stakeholders can find benefit sharing mechanisms and increase the acceptability of the package.

Conclusion

Modelling packages of technologies in a landscape rather than individual technologies allows taking synergies that emerge from the combination of technologies along the landscape slope into account. Some of the technologies are relatively general and need to be adapted to site-specific conditions. In this example, orchard had to be split into mango and apple trees, as these have very different growing conditions. One could easily add other perennial trees into this list, such as coffee or avocado. Impacts of the implementation of packages on livelihoods are multi-dimensional and are likely to result into trade-offs that are weighted differently by different stakeholders. It is likely that there are not only winners but also losers, at least in the short term. It is therefore important that packages are implemented in a bottom-up approach allowing stakeholders to negotiate and come up with benefit sharing mechanism.

Example 3: Reducing methane and carbon dioxide emissions from livestock and pasture management in the tropics ((adapted from Thornton and Herrero, 2010))

As the demand for livestock products in developing countries is projected to nearly double by 2050, competing demands for natural resources will intensify, and it will be a challenge to balance livestock production, livelihoods, and environmental protection. Livestock are also a large contributor to the climate change problem. Livestock systems will therefore need to adapt in the future, requiring significant changes in production technology and farming methods. Livestock production is likely to be required to play a much greater role in reducing GHG emissions. Livestock keepers could indeed mitigate some of these in various ways. This example compares four livestock and pasture management options aimed at reducing the production of methane and carbon dioxide in the mixed and rangeland-based production systems in the tropics: (i) improved pastures, (ii) intensifying ruminant diets, (iii) changes in land-use practices, and (iv) changing breeds of large ruminants.

Description of options

We look at the impacts of adoption of improved pastures, intensifying ruminant diets, changes in land-use practices, and changing breeds of ruminants for two levels of adoption: complete adoption, to estimate the upper limit to GHG reductions, and optimistic but plausible adoption rates taken from the literature, where these exist Table 9.

Table 9 : description of livestock related interventions

Option	Region	System	Gas affected	Changes evaluated
1. Adoption of improved pastures	CSA	LGH	CH_4, CO_2	Cerrado vegetation to *Brachiaria* spp. pasture: digestibility increase, impacts on animal productivity Carbon sequestration (9) Restoration of degraded soils (10) Area adopted: best case from Central America, 1990–2003, 1.3% per year (30% to 2030); average of five countries, 0.6% per year (11)
2. Diet intensification				
(a) Stover digestibility improvement	SSA, SA	MRA, MRH, MRT, MIA, MIH, MIT	CH_4	Stover digestibility increase by 10%, impacts on animal productivity Adoption rate: 43%, maximum observed for genetically improved dual-purpose cowpea in West Africa (12); generally much lower rates (<10%) are observed or expected (13); 23% to 2030 used here (1% per year)
(b) Grain supplements	SSA, SA	MRH, MRT, MIH, MIT	CH_4	Grain supplement: increase from 0.5 to 2.0 kg per head per day, impacts on animal productivity Adoption rate: 23% to 2030 assumed (1% per year). In the absence of data, similar adoption rates to agroforestry-based supplements may be plausible
3. Land use				
(a) Carbon sequestration in rangelands	CSA, SSA	LGA, LGH, LGT	CO_2 (CH_4)	Changed carbon sequestration rates (10) (Methane production at intermediate stocking rates: not evaluated here) Complete adoption
(b) Increasing agroforestry practices	CSA, SSA, SA, SEA	MRH, MRT	CH_4, CO_2	*Leucaena* spp supplement of leaves, animal performance: Adoption rate: 1% per year, 23% to 2030 assumed, plausible for the best case (14) Carbon sequestration per ha: average lower limit for different tropical agroforestry systems (15)
4. Changing breeds of large ruminants	CSA, SSA, SA, SEA	LG (meat), MRH, MRT, MIH, MIT (dairy)	CH_4	Local to a cross-bred animal: animal productivity, meat in the LG systems and milk in the MRH/T and MIH/T systems Adoption rate: 29% to 2030 assumed, based on Kenya's adoption of crossbred dairy animals, the best case in East and Southern Africa (16)

Identification of recommendation domains

Each of the options described in table xxx above can be matched to specific livestock production systems (LPS) and regions. For both of these criteria spatial data are available and the recommendation domains for the options can therefore be mapped (figure 7).

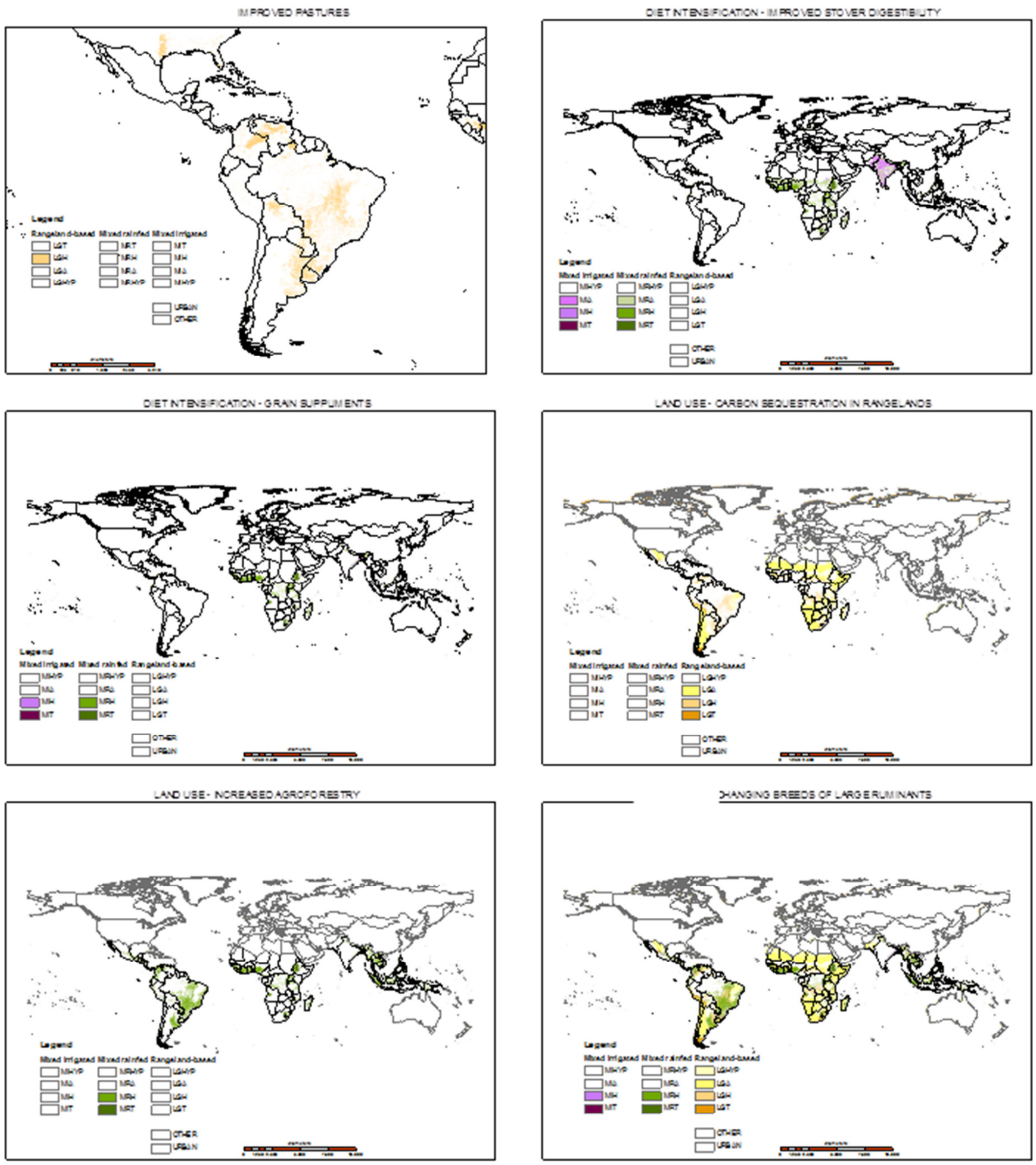


Figure 7 : recommendations domains for the different options

The affected

A Geographical Information System (GIS) was used to estimate the area covered by and calculate the number of people and animals in each of the recommendation domains (Table 10).

Table 10 : computation of the number of affected.

	Area (000s km2)	Human population (000s)	Cattle (000s)	Pig (000s)	Poultry (000s)
1. Improved pastures	1,700	12,700	1,100	3,800	121,900
2a. Diet - stover	8,700	918,100	6,700	18,200	638,600
2b. Diet - grain supplements	2,800	316,600	1,700	8,300	277,800
3a. Land use - grassland	17,200	124,500	3,100	13,600	429,800
3b. Land use - agroforestry	7,700	401,200	5,100	49,800	1,400,300
4. Changing breeds	27,200	725,800	725,800	9,100	80,200

Impact assessment

We estimated the impacts of the six options from table xxx on the production of CH4 and CO2. Results are shown in Table 11, in terms of the amount of CH4 produced per ton of milk and meat, and the number of bovines needed to satisfy milk and meat demand in 2030 for the region and systems shown (i.e., it is assumed that demand for these livestock products is satisfied from within each system in each region). Methane production was calculated separately for milk and meat, with due regard to the estimated proportions of dual-purpose animals in each system and by splitting the herd into milk-producing animals (adult females) and meat-producing animals (males and replacement females). Results also are shown for the amount of CO2 equivalent (CO2-eq) mitigated in relation to the three pathways considered, where these come into play for the different options: a reduction in livestock numbers associated with diet improvement, the carbon sequestered via restoration of degraded rangelands, and the extra carbon sequestered as a result of land-use change, expressed as Mt CO2-eq. Results for all options except 3a are shown for two levels of adoption: for 100% adoption rates in the systems and regions considered for each option, to define the upper limit of mitigation potential; and for an optimistic but plausible adoption rate taken from the literature.

Table 11 : impacts of the different livestock related interventions

Option	CH_4 production (kg) per t of Milk	CH_4 production (kg) per t of Meat	No. of bovines ($\times 10^6$) needed to satisfy demand in 2030 for Milk	No. of bovines ($\times 10^6$) needed to satisfy demand in 2030 for Meat	Mitigation of CH_4 via reduction in bovine nos. (Mt CO_2-eq)	C sequestered via restoration of degraded pastures* (Mt CO_2-eq)	C sequestered via land-use change (Mt CO_2-eq)	Total mitigation (Mt CO_2-eq)
1. Adoption of improved pastures in LGH systems in CSA								
Cerrado	78	1,552	45.5	45.5	—	—	—	—
100% adoption[†] of *Brachiaria* pasture	31	713	14.7	16.8	7.4	23.5	13.5[‡]	44.5
30% adoption[†] of *Brachiaria* pasture	64	1,300	36.2	36.9	2.2	23.5	4.1[‡]	29.8
2a. Diet intensification: stover digestibility improvement in MR, MI systems in SSA, SA								
Baseline diet[§]	58	1,958	490.1	490.1	—	—	—	—
100% adoption[†] of stover with 50% digestibility (from 40%)	25	548	177.0	114.3	61.6	—	—	61.6
23% adoption[†] of stover with 50% digestibility (from 40%)	50	1,634	418.1	403.6	14.2	—	—	14.2
2b. Diet intensification: grain supplementation in MRH, MRT, MIH, MIT systems in SSA, SA								
Baseline diet[§]	58	1,958	148.0	148.0	—	—	—	—
100% adoption[†] of increasing grain supplementation from 0.5 to 2 kg/head/d	18	395	39.3	22.5	22.1	—	—	22.1
23% adoption[†] of increasing grain supplementation from 0.5 to 2 kg/head/d	49	1,598	123.0	119.1	5.1	—	—	5.1
3a. Land use: restoration of degraded pastures in the LG systems in CSA and SSA								
In CSA	—	—	—	—	—	53.6	—	53.6
In SSA	—	—	—	—	—	96.7	—	96.7
3b. Land use: increasing agroforestry practices in the MRH, MRT systems in CSA, SSA, SA, SEA								
Baseline diet[§]	58	1,958	287.6	287.6	—	—	—	—
1 kg Leucaena supplement replacing 0.5 kg stover and 0.5 kg concentrate (100% adoption[†])	25	523	103.9	59.2	40.3	—	102.7[¶]	143.0
1 kg Leucaena supplement replacing 0.5 kg stover and 0.5 kg concentrate (23% adoption[†])	50	1,628	245.3	235.1	9.3	—	23.6[¶]	32.9
4. Changing breeds of large ruminants in the LG (meat) and MRH, MRT, MIH, MIT (milk) systems in CSA, SSA, SA, SEA								
Local breeds	31	713	363.3	172.8	—	—	—	—
100% adoption[†] of crossbreeds	26	568	171.6	77.8	19.5	—	—	19.5
29% adoption[†] of crossbreeds	30	671	307.7	145.2	5.6	—	—	5.6

These estimates are highly indicative, because there are several limitations to the analysis. Although we attempted a breakdown by region and system, the true complexity of the changes examined is not comprehensively addressed. For example, option 2b, if adopted widely in a region, could have significant impacts on grain price, which could then translate into shifts in demand for grain for human food and for livestock feed. For most of the options considered, there may well be indirect impacts on natural resources that are not considered here. In addition to that, each of these options has a cost associated with them as well as socio-cultural trade-offs.

Conclusion

Comparison of options at observed or plausible adoption rates suggest that restoration of degraded rangelands in SSA and CSA has the highest mitigation potential, owing to the magnitude of degradation and rangeland extent, although there may well be issues associated with its implementation. Next is the agroforestry option, which sequesters carbon and intensifies diet quality to reduce animal numbers. Improvements in the use of improved pastures and crop residue digestibility have the next-highest mitigation potentials owing to their broad recommendation domains and the marginal reductions in CH4 production per unit of output that can be obtained. Replacing breeds has the second-lowest mitigation potential of the options considered here, mainly because larger animals have higher intakes and produce significantly more CH4 than smaller indigenous breeds, and this negates most of the benefit of increases in milk and meat production. Grain supplementation had the lowest mitigation potential, apparently mostly because of the relatively limited recommendation domain for this option.

Example 4: Targeting development strategies in the drylands of East and Central Africa ((adapted from Aboud et al., 2012)

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Introduction

The drylands of East and Central Africa support agriculture, livestock rearing, tourism and wild resource harvesting and play a critical role in ensuring national food sufficiency (Nassef et al., 2009). The most widely spread livelihood strategy involves mobile or pastoral livestock production. Natural disasters in East Africa, however, frequently spark calls for renewed efforts to transform, or even abandon, the area's prime livelihood system (Sandford and Scoones, 2006). A variety of alternative development strategies have been promoted in the drylands. We focus here on enhanced livestock production through the development of livestock markets, small- and large-scale crop production, and diversification of the pastoral livelihood with special attention to wildlife tourism.

Characterisation and mapping

The drylands in Eastern Africa are highly heterogeneous. Rangeland landscapes and the communities inhabiting them are not all the same and will respond differently to both management practices and changes in the environment. It is of crucial importance to take this complexity and heterogeneity into account when planning development strategies. It influences the applicability and impact of interventions, as well as the need for specific investments and policy support. Development strategies need to be targeted well and specific supporting policies need to be put in place. In the following sections we therefore take a look at the heterogeneity of the drylands along the aridity, population density and market access axes and present constraints and trade-offs for a number of potential development strategies and point to the necessary supporting policies. We then match specific strategies to so-called dryland development domains.

Aridity

Productive potential is widely regarded as a major constraint for rural development. In drylands, the potential for crop agriculture typically increases with humidity. Crop cultivation in dry sub humid areas is to some extent inevitable. The spread of crop production into drier lands can however hinder the mobility of pastoralists and also increase the conflicts between herders and farmers. As crop cultivation moves into drier areas, it typically exploits key resource patches, such as grazing reserves that are vital to pastoral production, removing a small but essential component from the bigger pastoral system. To ensure their resilience, integrity and sustainable management, rangeland ecosystems need to be managed at the ecosystem scale. Frequently this does not happen and rangelands become fragmented, disconnected and poorly managed.

Where crop cultivation is practiced, close integration with livestock keeping should be promoted, through for example fodder production, ensuring access to water resources and seasonal forage and the regulation of transhumance. Further, the soils of a rangeland get easily exhausted and therefore must rely on fertilizer supplements to support continuous crop production (Okello and Grasty, 2009). Supporting investments and policies need to be put in place to avoid abandonment of agricultural fields, and the consequent degradation that may take long to restore. To reduce the human-wildlife conflict it might be necessary to compensate for wildlife damage.

At the drier end of the spectrum, the focus is on increasing resilience, through risk management, diversification of the pastoral livelihoods and holistic natural resource management.

Population Density

As population density increases, greater emphasis is needed on diversifying the economy into non-natural resource based activities. The urban economy needs to be strengthened, so that a section of the population can successfully exit out of pastoralism. Access to credit and education complemented by infrastructural investments are needed for this. As permanent settlements appear and continue to grow, there is a need to ensure mobility and connectivity to key natural resources. Strengthening the urban economy needs to go hand in hand with regional planning so that the rural development is not compromised. There is an urgent need to plan and guide this currently spontaneous and uncontrolled process of pastoral urbanization (Little et al., 2008). High population density typically puts high pressure on bio-diversity. The delineation and protection of conservation areas can contribute to the protection of biodiversity and ecological functioning.

Population density is also a proxy for the availability of labour, which is an important input in pastoral systems, but might especially become a constraint when pastoralists diversify into non land related activities (CCER 2010). Higher population density may enable labour-intensive livelihoods and land management approaches(Baltenweck et al., 2004; Chamerlin et al., 2006) and stimulate the development of local markets and infrastructure. It also increases the local demand, and is likely to reduce transaction costs (Pender et al. 2006).

Market access

Poor infrastructure, and insecurity, increases the costs and risks of livestock trading in remote areas (Barrett 2001, Little 2000). While the proximity to markets increases the number and range of options open to those interested in livelihood diversification.

At greater distance from the marketplace, pastoralists are less able to dictate or respond to terms of trade and are less able to sell little-and-often. This creates liquidity issues, which are compounded by the inability to sell when prices are high and save for a later date (Davies 2006). Hence tailor-made pastoral banking has particular pertinence, allowing pastoralists to take advantage of the high production in the good years and buffer against losses in the bad years. These services should recognise cultural and informational constraints. In addition to providing bank services, public investments in roads and infrastructure, household level processing and collective marketing can help to overcome some of the difficulties in accessing the markets.

The transaction costs associated with distance from markets and the need to sell in bulk could be a disincentive to diversification: the more economic activities that are engaged in, the greater the cumulative transaction costs. Hence it may make sense to invest in specialist pastoral production. When their herd size demands it, pastoralists can then move further from markets and access higher quality but distant pastures.

Dryland Development Domains

Factors such as aridity, access to markets and population pressure influence the constraints faced and the opportunities present for both pastoral and non-pastoral communities in the drylands. Based on these three factors, a dryland development domain map was developed for eastern and central Africa (fig 3). The domains developed were:

1. LLL: remote and sparsely populated arid and semi-arid areas
2. LLH: remote but relatively densely populated arid and semi-arid areas
3. LHL: well-connected but sparsely populated arid and semi-arid areas
4. LHH: well-connected and relatively densely populated arid and semi-arid areas
5. HLL: remote and sparsely populated dry sub-humid areas
6. HLH: remote but relatively densely populated dry sub-humid areas
7. HHL: well-connected but sparsely populated dry sub-humid areas
8. HHH: well-connected and relatively densely populated dry sub-humid areas

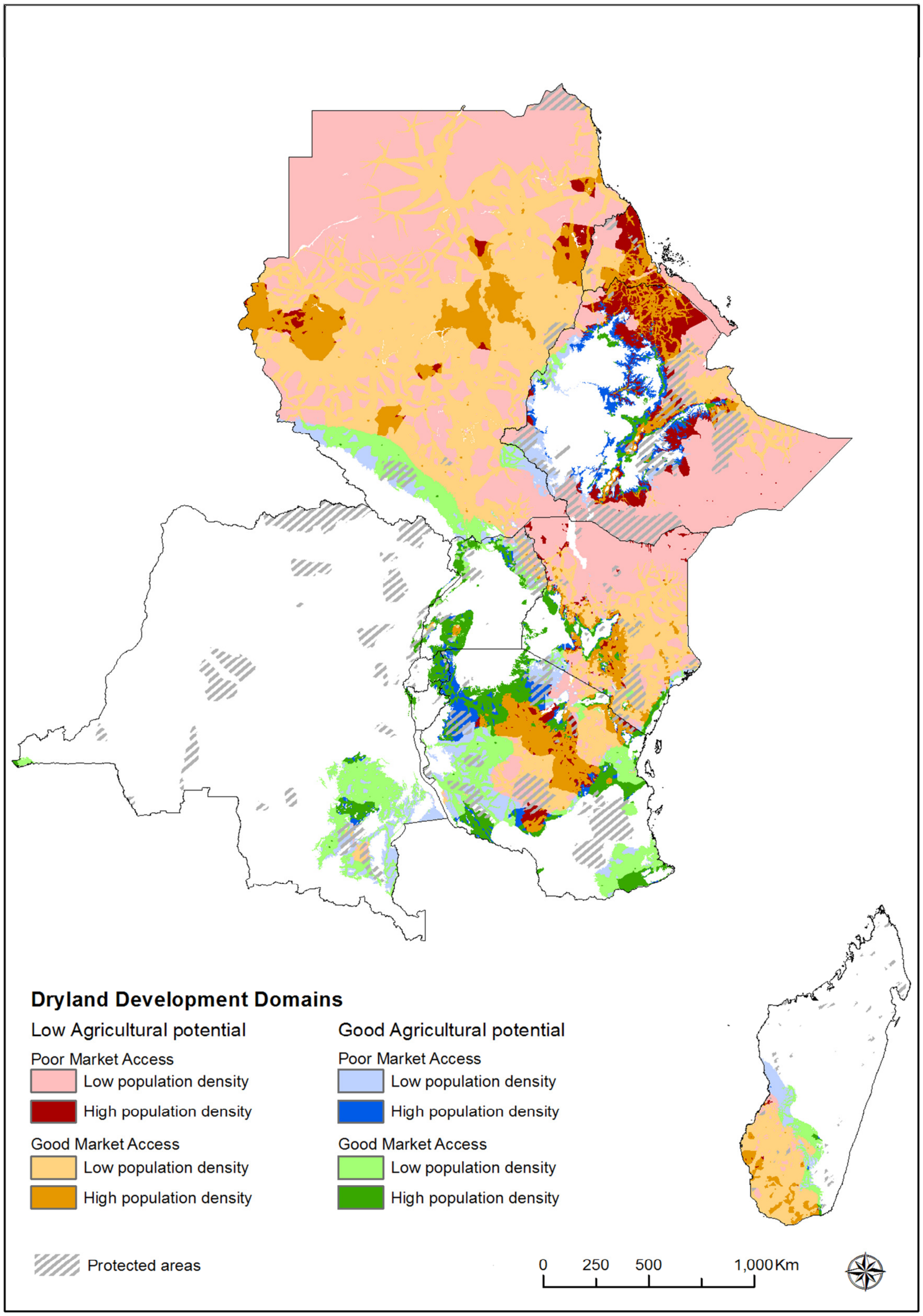

Figure 4 ***: The dryland development domains in the ASARECA region***

Each of these domains exhibit comparative advantages for different livelihood strategies and demand different policy actions or investments. In the next few paragraphs, we describe each of the domains and indicate strategies with good development potential.

LLL

This domain is the typical pastoral livelihood zone. The potential for rainfed agriculture is low to absent in most of the domain, with a short growing season, very high rainfall variability and soil and fodder availability constraints. Depending on the local circumstances there is potential for diversification through natural products, carbon sequestration, and possibly also wildlife tourism and community-based conservancies. At the same time, there is potential to enhance the pastoral livestock production through increased market participation and appropriate safety net strategies. It will be important to ensure access to feed and water through mobility or alternative smart investments.

LLH

This domain differs from the previous one in terms of population density. Although both the agricultural potential and the connectivity to markets are low, we find a relatively higher population density here. A considerable portion of the population is engaging in non-pastoral livelihood activities, with cattle becoming relatively more important than goats as compared to the low density remote (semi-)arid regions. The relatively high population in this domain clearly puts pressure on the traditional pastoral livelihood strategy, but the associated high labour availability could be taken as an opportunity to diversify in other activities.

LHL

The third domain in the arid/semi-arid region is characterized by relatively short travel times to the markets but low population density. It covers a vast land area and is a very important livestock production zone. Due to aridity, short growing season and high variability, this is another domain without potential for rain-fed cropping. With its relative proximity to the markets, the potential for increased market integration of the pastoral livestock production is, however, evident. Coupled with maintaining mobility and well-functioning safety nets, the livestock production can be increased. There is equally an opportunity for the pastoral livelihoods to be complemented /diversified with some other market-oriented activities, such as small trade, collection of natural products, etc. These areas are also prone to be the subject of land speculation, as investors become interested in areas with good market access but cheap land.

LHH

The last of the domains in the arid and sub-arid region is the one with good market access and high population density. This is an area where, due to the high population pressure, high-risk cropping/marginal agriculture is practiced by many and quite high crop-livestock integration can be found. Due to the proximity to the markets and good labour availability, diversification and a move away from livestock keeping for some portion of the population is feasible.

HLL

This is the first of the dry sub-humid domains. The growing season is a bit longer and the rainfall variability a bit lower than in the arid/semi-arid DDDs. With targeted investments and market support, there is huge potential to enhance the livestock production in this domain. There is also potential for large-scale agriculture but the trade-offs in terms of loss of biodiversity, soil degradation, soil carbon loss, loss of key dry season pasture and the negative effects on livestock production in the wider area will have to be taken into account.

HLH

The smallest of the domains, the HLH domain is home to almost 9 million people. With 17% of its area protected and still an average population density of 65 per square kilometre, this is a domain in which hardly any rangeland can be found. Diversification and exit are the most obvious strategies here. While infrastructural investments and market support are crucial for any kind of development in the HLH domain.

HHL

The third domain in the dry sub-humid area is the well-connected but sparsely populated domain. The area is relatively accessible and there is good potential for increased market integration of the pastoral livestock production. There is also an opportunity for the pastoral livelihoods to be complemented /diversified with some other market-oriented activities, such as small-scale as well as large-scale cropping, small trade, collection of natural products, etc. Again, trade-offs between the different strategies are important to keep in mind.

HHH

The HHH domain with its relatively good agricultural potential, proximity to the markets and labour availability has a good potential for livelihood diversification and commercialization.

The affected

More than 132 million people live in the dryland area of East and Central Africa**Error! Reference source not found.**. 41.5 million or almost one third of these people live in the LHH domain, a quarter in the HHH domain and about 17% in the LHL domain (figure 4).

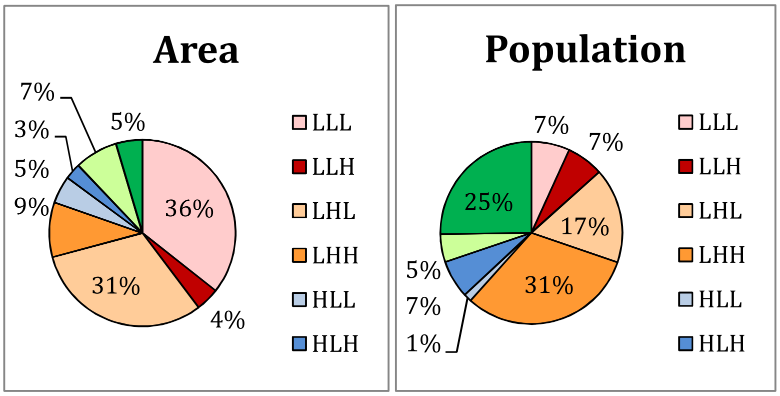

Figure 5 : area and population distribution in the dryland development domains

The most widely spread livelihood strategy in the East and Central African drylands involves mobile or pastoral livestock production. A number of households, however, opt to complement their income from the livestock production through a diversity of alternative activities. Some herders remain in the sector but are diversifying their income while sustaining their pastoral livelihood. There is also a potential to migrate out of pastoralism into non- or marginally livestock related activities. Investments geared towards supporting pastoralism and biodiversity will affect pastoralists and non-pastoralists in a different way.

Another challenge is presented in terms of spatial and temporal scales. The drylands are complex socio-ecological systems with many levels. Short-term benefits can be outlived by long-term negative consequences. Interventions with positive outcomes at the local level often have disastrous effects when evaluated at a larger geographical scale.

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The impacts

Table 12 : potential impact at farm scale (pastoralist, non-pastoralist) and at landscape scale

		Pastoralists	*Non-pastoralists*	*Landscape*
Development of livestock markets	positive	increased income	employment	increased livestock production
	negative	restricted mobility		
	challenge	anti-competitive bottlenecks	social inequality	

Wildlife tourism	positive	generating income	generation of income and jobs	increased biodiversity
	negative	restricted mobility		decreased livestock production
	opportunity			PES
	challenge	social inequality	social inequality	
Crop production	positive		increased crop production and income	
	negative	restricted mobility		decreased livestock production, deforestation, biodiversity loss, degradation, pollution, spread of water-borne diseases
	challenge	social inequality	social inequality	

Connecting pastoralists to the markets and integrating the pastoral meat and milk production into the livestock value chain presents an opportunity for increased incomes. Special attention will have to be paid to generate employment throughout the supply chain, so that this commercialization is equitable and not only to the advantage of the better-off pastoralists and middlemen.

Proximity to markets and urban centres affects the number and range of options open to those interested in livelihood diversification. According to research undertaken by (Little, 2005)pastoralists residing less than 40 km from towns typically have more alternative income generating options than those living further away. According to (Little et al., 2008)Little et al. (2008), however, there appears to be a trade-off between the disruptions to the pastoral production system brought about by restricted mobility and increased benefits of access to markets. They argue that the opportunities to move opportunistically in response to unpredictable rainfall patterns and forage production are most constraint near towns where markets are found but more favourable in remote rangeland zones. In addition, there are different market challenges to address for people living closer to markets. For those people is important to put policies and institutions in place that remove “anti-competitive” bottlenecks, such as market exclusions and distortions by trader cartels(Barrett and Luseno, 2004).

Wildlife tourism generates significant income in many countries of the East-African region. It also generates jobs, both formally and informally. On the downside, land is sometimes lost to national parks and conservation areas, with the revenue not necessarily directed back to the pastoralist population, but rather excluding them from exploiting the grazing potential and restricting their pastoral mobility. Some wildlife tourism is organized in community-based conservancies and promotes integrated livestock-wildlife conservation. If at the same time, payments for environmental services (PES) could be put in place for biodiversity conservation, conservation of the environment and reduction of poverty could be combined and pastoralists could benefit from an income diversification. Sales of livestock plus payments for environmental services could then stabilise income sources, leading to higher food security and reduced vulnerability. Care needs to be taken that these payment schemes don't lead to inequity as it is only the well-educated or more resourceful that have the information to access payments for ecosystems services. Experience in Kenya, for example, shows that money generated by parks and community sanctuaries from tourism revenue mostly go to local elites, foreign tour investors or the government ((Norton-Griffiths and Said, 2010). The participation of poor households in PES are limited by among others, high transaction costs, institutional and technical barriers, lack of information, and weak capacity for negotiation, property rights and especially land tenure (Kosoy and Corbera, 2010; Miranda et al., 2003; Zbinden and Lee, 2005).

The spread of crop production into drier lands will provide diversification options for some, but can at the same time hinder the mobility of pastoralists and therefore increase the conflicts between herders and farmers. As crop cultivation moves into drier areas, it typically exploits key resource patches that are vital to pastoral production, removing a small but essential component from the bigger pastoral system. In the long term productivity might decrease as investors buy large areas of land that can be put into alternative production at the expense of grazing land and biodiversity. The reduction of mobility in semi-arid and arid pastoral systems increases the risk of degradation: it concentrates grazing pressure on the resource and reduces the opportunities for resting parts of the vegetation, while at the same time remote areas become less frequently utilized and may lose productivity in the absence of periodic grazing. Other potential negative outcomes of this intensification include deforestation, biodiversity loss, degradation of soil and water resources, illness caused by crop chemicals, vector-born arbo-viruses and social inequity.

The Worldbank and FAO (2009) talk about a considerable potential for large-scale commercial farming in the relatively fertile and sparsely populated drylands. However in the long term productivity might decrease as investors buy large areas of land that can be put into alternative production at the expense of grazing land and biodiversity. This could in turn result in more vulnerable and dependent communities and cultural erosion.

Conclusion

The drylands in Eastern and Central Africa produce a lot of highly valued services, ranging from meat and milk over biodiversity and carbon to tourism and cultural values. When planning the use of these lands, choices will have to be made. The impacts of the available livelihood options will have to be evaluated against different objectives, such as increasing food production, enhancing livelihoods (in terms of income or food security), and maintaining biodiversity or environmental sustainability, and weighted accordingly. While some land use combinations enhance complementarities, others involve making hard choices and complex trade-offs.

In summary, there's a need to optimize the system/wider landscape and look far beyond the maximum use of separate patches. An optimized overall use of the dryland areas in Eastern Africa necessitates careful regional land use planning, taking into consideration trade-offs at the landscape scale. The concept of development domains can help planners and decision makers thinking through the nature of investments and supporting policies needed when evaluating the wide variety of available livelihood options and land use systems. There is also a pressing need to include communities in the planning. Pastoralism and pastoral lifestyles are unique and tailored to inhabit and use the drylands as efficient as possible, through use of traditional knowledge system and cultures. This resilient and adaptive knowledge of the pastoral people should be incorporated in the national policies and strategies where appropriate.

The development of rural livelihoods typically involves a mix of interventions. Each of them with different potential impacts on the direct and indirect landscape benefits. Total Economic Valuation can be used to provide valuation of the ecosystems services that are provided by the different land use options, touching on the potential opportunity costs of different options at the landscape scale.

Example 5: Adaptation options in the marginal cropping areas of sub-Saharan Africa

Introduction

The impacts of climate change are expected to be generally detrimental for agriculture in many parts of Africa. Overall, warming and drying may reduce crop yields by 10 to 20% to 2050, but there are places where losses will be much more severe. Increasing frequencies of heat stress, drought and flooding events will result in yet further deleterious effects on crop and livestock productivity. These impacts will be highly heterogeneous, both spatially and temporally. Conditions for crop growth in some places in the highlands of sub-Saharan Africa (SSA) may improve because of increasing temperatures and rainfall amounts, and this could provide smallholders with opportunities to intensify and/or diversify production in these areas. In other places, the changing climate will affect the livelihood strategies of rural people, which will need to change if food security and provide income-generating options are to be preserved. The areas of Africa that are likely to be affected in this way are those that are already marginal for crop production. As these become increasingly marginal for cropping, through a combination of increasing temperatures and changing rainfall amounts and patterns, householders will need to consider alternatives to their current enterprises. Given the heterogeneity of the likely impacts of climate change and of households' ability to deal with it, information on the likely impacts is needed so that effective adaptation options can be appropriately targeted. In this example, we identify "transition zones" in SSA where climate shifts between now and the middle of this century will make cropping increasingly risky, characterise these zones in terms of their human and animal populations and poverty rates, and identify some of the adaptation options that may be appropriate.

Identifying and characterising the transition zones

To identify the transition zones of SSA - those areas where cropping may become increasingly difficult in the future - we estimated the probabilities of failed seasons for current and future climate conditions. Methods are outlined in detail in Jones and Thornton (2013). Briefly, for all of SSA, we calculated three variables from 100 years of simulated daily weather data:

- Length of growing period (LGP), the average number of growing days per year;
- Failure rate of each the primary growing season: this is the failure rate of the longest (average) growing season;
- Reliable Crop Growth Days (RGCD), defined as the season length multiplied by the success rate (1 – the failure rate) of the season, a proxy for the long-term expectation of the number of reliable cropping days per year, which in some places may be spread out across several seasons.

These three variables were calculated for current conditions using WorldClim (Hijmans et al., 2005)), and then for conditions in the 2050s using the four combinations of two different climate models and a higher and a lower greenhouse-gas emission scenario. The dataset of Mitchell et al. (2004) was used, and the relatively coarse climate model output data were downscaled using the methods of Jones and Thornton (2003).

To define the transition zones, we used maize as the indicator crop; maize cropping is generally considered to be marginal in areas with an LGP of between 121-150 days per year, and only some of the millets may be appropriate in areas with a shorter LGP(Nachtergaele et al., 2002). Taking the lower limit of this range as a conservative cut-off point for maize cultivation, 120 days LGP can be expressed in RCGD equivalents, which we found to be approximately 90 RCGD. We defined "transition zones" to be areas with 90 or more RCGDs per year in 2000 but with fewer than 90 RCGDs in the 2050s. These areas are mapped in Figure 1, for the mixed crop-livestock, rainfed, arid-semi-arid systems of SSA (Seré and Steinfeld, 1996). In these systems, season failure rates are projected to increase from 18 to 30%, depending on the GCM-scenario combination, an increase in season failure from nearly one year in six to one year in three. In the same systems, RCGDs decrease from 99 to 73 for so for the high-emission scenario.

These transition zones are characterised in Table 1 in terms of their area, human population, cattle, sheep and goat populations, and three poverty proxies, stratified by accessibility. In total, these zones account for up to 3% of the land area of the continent, and currently support up to 35 million people and 23 million Tropical Livestock Units (TLU) of cattle, sheep and goats. These areas have a mean accessibility index of about 500 (i.e., a travel time to the nearest centre with a population of at least 250,000 people of 500 minutes). These zones have higher levels of poverty than the continental average, in terms of infant mortality rates, stunting rates (chronic under-nutrition), and wasting rates (acute malnutrition). The poverty proxies in the poor accessibility transition zones are substantially higher than in the good accessibility areas. Not only will climate change impacts affect the poorer zones disproportionately: season failure rates also increase disproportionately, from one year in ten to one year in four, in the remoter transition zones.

Options for adaptation in the transition zones

What are the options for householders in these transition zones? Traditionally, pastoralists, agro-pastoralists and croppers over the centuries have invented a very diverse portfolio of ways to deal with the spatial and temporal variability of production potential (or the ability of specific pieces of land to support animals and crops). Three are highlighted below.

Modify the relative emphasis placed on crops and livestock within the household: as cropping failure rates are projected to increase markedly in the future in the marginal areas, households might consider placing more emphasis on their livestock enterprises. Particularly for households located relatively closely to large human settlements, there may be options for both integration of livestock systems into the market economy and for off-farm employment opportunities. For households that are more remote, both market and off-farm employment opportunities may be much more limited. In many of these areas, livestock are already important: in the future, the importance of livestock as providers of calories and income to such households will continue to increase.

Modify the livestock species kept and/or herd composition: other options to adapt would include changing the species of livestock kept, and changing the composition of the herd in appropriate ways. There are various examples of this. For instance, the Samburu of northern Kenya are traditionally a cattle-keeping people and have long had close associations with several camel-keeping neighbours. However, in the last two or three decades they themselves have begun to adopt camels as part of their livelihood strategy, as their cattle economy has declined because of drought, cattle raiding, and epizootics(Sperling, 1987). Some households change their herd composition within species; FulBe herders in Nigeria have changed their cattle breeds to include species that can survive better on browse rather than on hard-to-come-by grass in the semi-arid zone (Blench and Marriage, 1999)(Blench et al., 1999). Many pastoralists keep a mixture of grazers and browser, they often prefer indigenous breeds to cross-breds or exotics as indigenous breeds tend to be more resistant to disease and droughts, and when feasible they concentrate on building up the number of female animals in their herds to facilitate herd replacement after drought(Huho et al., 2011).

Modify the crops they plant: opportunistic cropping is very common throughout the marginal areas of SSA, and recent survey evidence suggests that it is increasing rather than declining, even though there are widespread perceptions that the marginal areas are already becoming drier and weather more volatile (Thornton et al., 2011). Cassava is one crop that may have a considerable role in helping households to adapt in marginal cropping environments. Changes in cassava suitability over the next two decades have been estimated by Jarvis et al. (2012)(Jarvis et al., 2012) using the EcoCrop model and key climatic parameters. The percentage cassava suitability of each pixel in the transition zones in Figure 1 is shown in Figure 2 for current conditions and for the 2030s, using the mean projections of several climate models. Generally speaking, areas that are already highly suitable for cassava cultivation (the >67% category in Figure 2) remain so; particularly in tropical East Africa, areas that are currently not that suitable for cassava (the <33% category) become more suitable by the 2030s (the 33-67% category). Cassava suitability in the transition zones in the southern latitudes of the continent are not projected to change that much. These results suggest that even in these marginal cropping areas, expansion of cassava cultivation could be an important adaptation option for households as the climate warms in the coming decades.

Conclusions

The kind of spatial analysis outlined here can contribute to targeting work not so much via increased understanding of the key processes involved (that may come from many other different sources) as through providing detail and local context as to who may be affected, how, and where. The transition zones identified are patchy, quite numerous, and often rather small in area, and this type of analysis can start to address the considerable spatial variability associated with both the impact of climate change and different households' ability to deal with this impact. We are already undertaking more nuanced analysis of possible adaptation options at the level of the household, using household models to assess what the impacts may be of different alternatives on key outcome indicators such as household food security and income (Thornton et al., 2011). This kind of refined targeting information can be expected to be of considerable value to research and development organisations with a specific focus on poor and highly vulnerable people.

Conclusion

The suitability and adoption of development interventions in agricultural systems depends on a variety of bio-physical and socio-economic factors. While their impacts -when adopted and out-scaled- are likely to be highly heterogeneous, not only spatially and temporally but also in terms of the stakeholders affected. In this document we provide generic guidelines for evaluating and prioritising potential interventions through an iterative process of describing the options, mapping out recommendation domains and estimating impacts. We also demonstrated the application of this generic multi-stage framework in a variety of fields related to agricultural development. We've shown both qualitative and quantitative implementations of the framework. The same iterative multi-stage process can be run through by experts, based on expert knowledge and consultation or with several stakeholder groups and in either qualitative or (semi-)quantitative fashion. The framework provides a comprehensive step-by-step guide for designing and planning rural development interventions. As such, we hope to contribute to the inclusion of such important considerations when agricultural innovations are targeted and scaled out.

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