Treesilience

An assessment of the resilience provided by trees in the drylands of Eastern Africa

World Agroforestry Center
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January 2014

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An assessment of the resilience provided by trees in the drylands of Eastern Africa

Edited by Jan de Leeuw, Mary Njenga, Bob Wagner and Miyuki Iiyama

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Foreword

This book is timely as it addresses the role of trees in enhancing the resilience of livelihoods and economies in the drylands of Eastern Africa. The region faces severe and complex challenges including recurrent drought and flash floods that progressively erode livelihoods in pastoral, agro-pastoral and agricultural communities. High poverty levels in the regions' drylands aggravate the impact of these natural hazards, increase vulnerability and weaken people's ability to cope and recover. The extreme weather events associated with climate change and variability has continued to increase in the region. The need to develop appropriate adaptation measures including the necessary knowledge base to enhance resilience and enable communities' cope with impacts and increased risks of climate change has become a priority.

This book contributes to the national and regional efforts to support actions to increase household assets needed to reduce vulnerabilities of affected communities. The disaster brought about by the 2010-2011 drought heightened awareness that the drylands of Eastern Africa are particularly vulnerable to shocks and led to a call for addressing the root causes of vulnerability in the arid and semi arid areas (ASALs) of the region. This resulted in a wide range of initiatives from international to national and local level such as for example the IGAD-led Horn of Africa Initiative that brings together development partners to increase and better coordinate investment in resilient development. Governments in the region have developed their National Adaptation Plans for Action on Climate Change (NAPAs) and Country Programmes on Ending Drought Emergencies as part of the outcome from the IGAD/EAC Summit of 2011. In addition, a wide range of national, regional, and international partners have pledged to coordinate both humanitarian and development activities around the common agenda of resilience. The Kenyan Government, for example, established the National Drought Management Authority (NDMA) in 2012 to coordinate management of drought risks and enhance adaptation to climate change. There is also effort to ensure that these resilience enhancing initiatives fit into the long-term development plans such as the Kenyan Vision 2030 which aims to develop drought and climate change resilient development strategies.

Accessible knowledge is important to support these initiatives, particularly for identifying opportunities to achieve greater resilience. Dryland savannah woodlands and dry shrublands dominate large parts of the drylands of Eastern Africa, and the question is how can trees enhance resilience and contribute to economic development. Yet, existing knowledge on the role of trees to enhance resilience is widely scattered and inadequate. The consultative process that led to this book addresses this knowledge gap; it brings together a range of evidence and experts from the region and beyond and resulted in the compilation of dispersed knowledge.

The information contained in this book was compiled in a relatively short period of four months (June to October 2013). It was based on a consultative process among a larger group from which fifty people from the Eastern African region and beyond was selected to attend a one-week write shop. In retrospect, it is impressive to see how a one-week write shop resulted in a comprehensive book of more than 150 pages. The write shop model is apparently very effective in extracting and synthesizing the dispersed knowledge available within a community of experts.

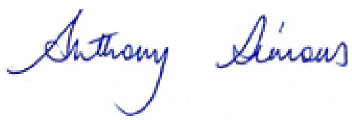
The benefits of trees in drylands are manifold. Some are direct benefits and generally appreciated such as the provisioning of food and wood fuel. Others, such as the support of primary production or the regulation of the water cycle, are indirect, underappreciated and frequently ignored. For this reason, the book authors have taken an ecosystem service perspective as an approach to do justice to the direct and the indirect benefits that people derive from trees in drylands. Such a perspective on resilience makes the book innovative, because it is to our knowledge the first attempt to link resilience to ecosystems services. Intuitively, this is an area of much potential for societal impact and innovative scientific work and we propose to stimulate further activity at the interface between resilience and ecosystem services.

Dryland agroforestry systems, which combine trees with livestock keeping and crop production, provide a multitude of benefits to people. These agroforestry systems are multi-functional landscapes managed by people to supply the ecosystem services they require. The book rightfully stresses the importance of supporting ecosystem services that underpin the provisioning of foods and other commodities from which people directly benefit. Multi-functionality implies various uses of land and trees, which are not always compatible. The book also indicates that unsustainable use and extraction of dryland resources may undermine the resilience that these systems can provide. This is particularly so for trees, which discontinue their role as resilience providers when ruthlessly cut, uprooted and overexploited. A reliable supply of tree-based resilience requires recognition of the importance to maintain and respect this natural capital. A secure tenure of trees and the land on which they grow is a first prerequisite to facilitate a more sustainable supply of tree-based resilience.

The knowledge and experiences compiled in this book form a strong basis to support those considering using trees to build resilience into the livelihoods of drylands' people. The effectiveness of tree based resilience interventions requires sound information and an enabling policy and institutional environment. The book identifies several knowledge gaps, which need to be addressed before full advantage can be derived from tree-based interventions. It further stresses the need for enabling policies and institutions to promote greater uptake of trees as resilience builders in drylands. We agree on its advice to work towards secure tenure of land and trees, and promote the institutions and partnerships to make this work.

Building resilience requires an integrated approach embedding climate change across all sectors and capitalizing on the available knowledge bases. We believe this book makes an important contribution to resilience building to protect the vulnerable communities of Eastern Africa from the impacts of climate change.

Dr. Tony Simons, Director General, World Agroforestry Centre (ICRAF)



James Oduor, CEO of the Kenyan National Drought Management Authority (NDMA)

Ali D. Mohamed, Member of IPBES (International Platform on Biodiversity and Ecosystem Services), formerly Permanent Secretary, Ministry of Environment and Mineral Resources of Kenya

Executive summary

Background

People in drylands are vulnerable to the effects of drought and climate change, particularly in the drylands of developing countries where high poverty levels limit their ability to cope. This is the case in the drylands of Eastern Africa, where the combination of endemic poverty and frequent drought have led to a situation where relief has overtaken development as the major area of investment.

In recent years it has been realized that there is a need for development, which rebuilds the drought resilience of the region's dryland economies. Trees can enhance resilience of livelihoods in drylands, but their exact contribution has been poorly explored.

Approach and structure

This book is the result of a consultative process, which brought together experts from Eastern Africa and beyond to synthesize and compile existing information on the role of trees in building resilience in the region's drylands. The group consisted of a mixture of experts with backgrounds in research, academia, government, farmers and development practitioners, and the book reflects the knowledge and perspectives of these various groups.

The book begins by describing the rationale behind the initiative followed by a clarification on the background and approach taken. Chapter three then describes the Eastern African region and argues why there is a need to build resilience in the livelihoods of communities living in drylands. Chapter four builds on this by introducing an ecosystem services perspective as the conceptual framework to explore the resilience offered by trees. Chapter five reviews the ecology, distribution and use of trees throughout the Eastern African region. Chapter six uses an ecosystem service perspective to review the various benefits that people derive from dryland trees. Chapter seven draws on experiences gained in development practices and presents and reviews 11 case studies of natural resource management. Chapter eight presents reflections of the write-shop participants on how best practice in resilience-building could be scaled up. A review of knowledge and information gaps regarding the contribution of trees in building resilience is presented in chapter nine, which is followed by a plan for possible follow-up action in chapter ten.

Findings and recommendations

The consultative process resulted in the following findings. **First**, although many people intuitively associate trees with resilience there is very little factual evidence on the role of trees in building resilience and the Natural Resource Management (NRM) projects that were reviewed rarely reported on or disseminated the resilience provided by the project interventions. Currently, information on trees in dryland NRM projects focuses on the possibilities for benefits through agricultural intensification. This reflects a wider lack of information on project-based experiences in resilience enhancement, which is understandable because the interest in resilience is relatively new. Given the need for resilience, it is important to develop capacity in resilience thinking in research and development. **Second**, the experts consulted suggested many possible ways through which trees provide resilience. These are described in detail in chapters six and seven. One common issue emerging from the review in these chapters is the need for an enabling environment, and the following three main areas were considered crucial: (i) the necessity of establishing secure tenure of land and trees, (ii) institutions to support an equitable and sustainable use and management of trees and (iii) partnerships among community, public and private parties. **Third,** resilience is a relatively new concept, which is poorly understood and hence rarely included in monitoring and evaluation (M&E)frameworks. There is need to develop concepts, procedures and practices in implementing resilience in policy and project cycles and for monitoring and evaluation of its impact. **Fourth**, while trees may offer resilience through supporting, regulating, cultural and provisioning ecosystem services, there is a tendency to ascribe the resilience-building effect of trees to the goods that trees provide while ignoring the other equally – if not more –important ecosystem services. **Finally**, local communities are the key players in the implementation of strategies to enhance the resilience of their livelihoods. They benefit from reliable information, enabling policies, better conceptualization and implementation and a more balanced approach to development efforts. As such their knowledge, perspective, vision and action form the basis of building greater resilience in the drylands.

These findings lead to the following recommendations

First, there is need for better information and knowledge management on the benefits that people derive from trees. Support is required for collecting, compiling and articulating evidence about the resilience-building role of trees. We recommend that special graduate-level study programs be developed among a consortium of universities and research organizations to address these knowledge gaps. Such information should be shared with as broad an audience as possible, perhaps by using mass media (internet/ YouTube, radio and broadcast TV) to share stories of tree-champions at work in the drylands.

Second, there is need to address tenure security, institutions and partnerships that support an environment which encourages land users to manage trees sustainably and benefit from the products and services that they provide.

Third, there is need for capacity development in resilience thinking and its integration in the entire policy and project cycles including monitoring and evaluation. Such capacity development should aim at down-to-earth approaches, linking natural resources, resilience and livelihoods in a manner that ensures that the concept is understandable and operational among partners in drylands development.

Fourth, there is need for a more balanced attention to all ecosystem services that provide resilience, because current attention focuses on direct benefits (e.g. the supporting services or goods provided by trees). Policy and projects are advised to pay particular attention to the frequently neglected indirect resilience benefits that trees provide (e.g. the supporting and regulating services).

Fifth, there is need to promote leadership among local stakeholders to take the initiative in building resilience of their livelihoods, a premise that should be embraced by future development efforts.

Chapter 1: Rationale

There has been a considerable increase in interest in drylands development over recent years. This attention is driven by the recognition that while African drylands have absorbed significant humanitarian aid over the last three decades, there has been comparatively little effort put into development that would increase people's resilience and reduce their dependence on aid. The re-awakened interest in drylands development has translated into support of livestock and crop-based development pathways and more recent efforts to foster resilience tend to focus on livelihood dimensions that revolve around these agricultural commodities. Here we wish to propose that agroforestry, that is, tree-linked production systems not only significantly support dryland livelihoods, but could also play a pivotal role in achieving a highly resilient and hence sustainable drylands development. However, the scientific and technical knowledge on trees and agroforestry in drylands and information on their contribution to dryland livelihoods is scattered, fragmented or siloed, and therefore often overlooked.

To address this lack of awareness, the World Agroforestry Centre (ICRAF), with support from DFID, set out to implement a consultative assessment process (following a structure similar to those in other assessment processes such as the UK-National Ecosystems Assessment), with the aim of increasing awareness and guiding decision-making and policies addressing trees and agroforestry in African drylands, and more specifically, in the countries of Eastern Africa (Horn of Africa). The outputs of the consultation process will be adapted to guide decision-making and policy development by parliamentarians, government officials, non-governmental organizations (NGOs), farmers' and pastoralists' associations and others. This will help ensure that trees in forests and agroforestry systems are managed and used such that they strengthen land users' resilience to the shocks they encounter in the Eastern Africa drylands.

Chapter 2: Mode of operation

As with other similar assessment processes, a team of the executing agency, ICRAF, invited a range of scientists, experts and practitioners of the CGIAR and other academic, research and development organizations within and outside eastern Africa to contribute their time and knowledge.

The ICRAF team also recruited 20 non-Nairobi based participants, 10 from the Eastern African region and 10 globally to attend a write-shop. The selection criteria for inviting persons for the write-shop were (i) has expertise in land management in drylands, drylands agroforestry and forest systems, (ii) has experience in the role and potential of trees in the developing world and (iii) has demonstrable writing skills. This resulted in a well-balanced mix of experts and practitioners in forestry, agroforestry, agriculture, ecology and the social sciences (see Annex 1). This group of specialists was commissioned to scan the current knowledge and extract from it what is relevant to decision and policymaking regarding the contribution of tree-based ecosystems and agroforestry ecosystems to the resilience of land users in eastern Africa drylands.

An outline and draft of this assessment book was shared by the end of the first week of July with all invited participants, with a request to provide feedback. The draft outline was revised before the write-shop upon reception of feedback from the experts. In preparation for the write-shop the participants were invited to rank their expertise on the various topics and to prioritize their preferences for contributing to specific sections of the book and the production of other communication products.

Before the write-shop a webpage on the project was created and a blog about the write-shop and another on its progress were posted. A policy brief was drafted during the workshop and ideas and an outline of a technical brief developed. The project team and stakeholders further developed these briefs after the write-shop (Annex 3). Further, the section on wood fuels (section 6.2.6) was used to develop a two-page fact sheet on wood fuels (Annex 3.3), which was presented during the United Nations Convention to Combat Desertification, Conference of the Parties (UNCCD CoP) meeting in September 2013 in Namibia. Finally, an article about the project was published in The Link Newsletter, Volume 5, an internal publication of ICRAF Eastern and Southern Africa.

The write-shop was hosted in mid-July [15^{th} to 19^{th}], at the ICRAF campus in Nairobi and backstopped by the organization's staff. At the outset the write-shop organizers presented to the team of experts the draft table of contents of the book, and allocated small teams of experts to initiate or complete sections according to each team's preference. The write-shop facilitator summarized the approach (see Figure 2.1) of review-ing the initial draft. To allow for optimal participation among the specialists, especially within the working groups, emphasis was given to assigning specific tasks [not everyone being equally proficient at writing] that go into strengthening the material. Some people worked on synthesizing existing documents, e.g. to identify impact-related knowledge on trees+resilience project initiatives in the Eastern African region, while others worked with ICRAF resource people to add illustrations [maps, diagrams, photos, etc] that help back up some points.

A critical aspect of any successful write-shop is striking a balance between small group work to achieve the writing tasks (or at the minimum generate good outlines and secure relevant, verifiable material to draw on later) and plenary sessions to provide time for presenting cases and sections, respond to queries about material and clarify statements. Capturing these and ensuring they are reflected in the final text makes the write-shop process a dynamic, shared learning experience and efficient in terms of rapid feedback and improving newly generated text. It was a challenge to keep track of the various pieces of text developed by the various groups and to ensure that these are available for further review. To manage this process use was made of DropBox, which allows sharing and editing text by multiple contributors. For an additional note on use of this advanced, but simple tool during and after the write-shop see the box on "DropBox Do's and Don'ts".

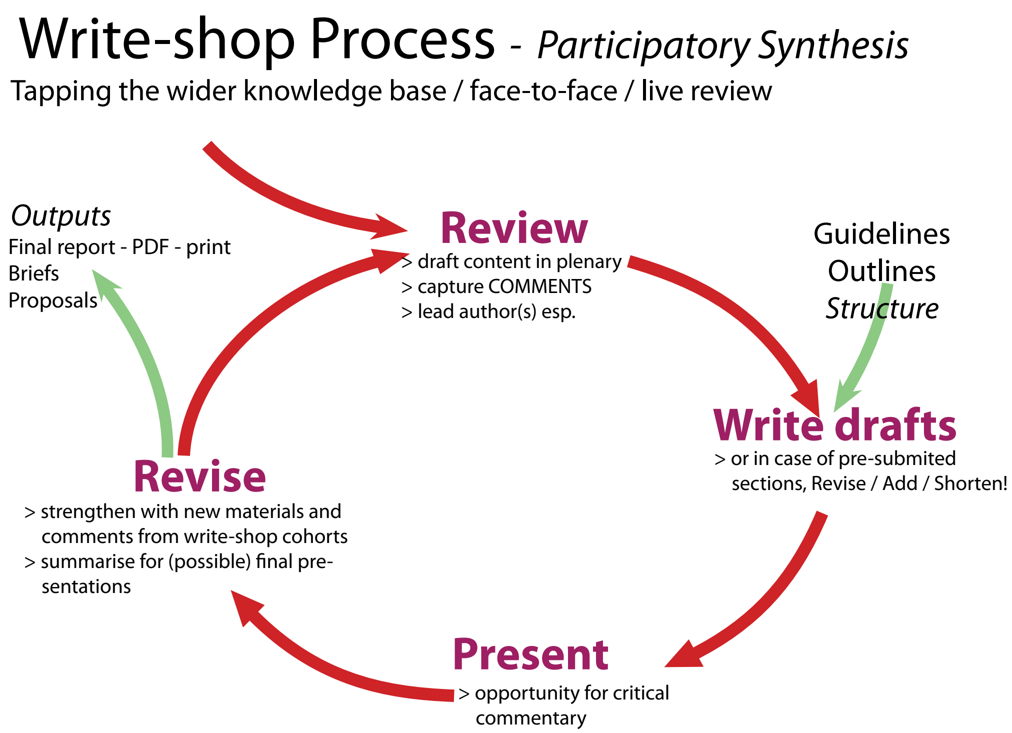


Figure 2.1. The review > compose > present > revise cycle

Finally, the findings of the write-shop were presented to a wider audience on the morning of the last day, Friday July 19th. On the closing day the management team developed a plan to complete the background book and communication products.

The consultative writing process continued after the write-shop during which chapters and sub-chapters were completed. Further consultation was carried out among the contributors where they ranked the importance of biodiversity in ecosystem services and results synthesized into a sub-chapter. Once each chapter or sub-chapter was completed, it was taken through independent review. Further review of the whole document was carried out by two independent people not involved in the write-shop after which it was copy edited.

DropBox Do's and Don'ts

DropBox is a free, easy-to-set-up and use file sharing software package [www.dropbox.com]. Using it will avoid a great deal of additional e-mail traffic and hunting for and downloading large attachments. It has the added advantage of automatically backing up all working files onto the 'cloud'. The write-shop facilitators chose to use it for rapid sharing of new material, organizing the many documents and working versions of the book and other outputs. Here are the lessons learned:

DO

- Be sure ALL invited DropBox users understand how it works, from day ONE of the write-shop.
- Have an Information Technology (IT) expert on call to assist people with downloading and installing the package on their laptops.
- *Remind* participants that working files should NOT be deleted, or moved among folders – such housekeeping tasks are only for the facilitators.

DON'T

- Assume everyone will take the time to set up and self-learn the ins & outs of the tool – some people learn faster than others, some might be too shy to even ask for help.
- Put 100% faith in the system – make periodic back-ups onto an external, secure hard drive *just in case.*

Chapter 3: The need for resilience in the drylands of Eastern Africa

Mary Njenga, Jan de Leeuw, Mick O'Neill, Pamela Ebanyat, Mareen Kinyanjui, Paul Kimeu, Hassan Adirizak, Koert Sijmons, Anton Vrieling, Maimbo Malesu, Alex Oduor and Philip Dobie

3.1 Classification and distribution of drylands

Drylands make up the vast majority of land in Eastern Africa (Figure 3.1). Drylands are characterized by water scarcity, and are defined as lands with an aridity index, the ratio between annual rainfall and annual potential evapotranspiration, of below 0.65. A further distinction in four dryland sub-systems is made into hyper-arid lands with an aridity index below 0.03, arid lands (0.03 – 0.20), semi-arid lands (0.20 – 0.50) and dry sub-humid lands (0.50 – 0.65). The map reveals that the majority of the Eastern Africa territory is classified as dryland. The semi-arid and the arid zone are the largest single dryland systems, followed by the dry sub-humid zone. A small fraction of northern Somalia is classified as hyper-arid.

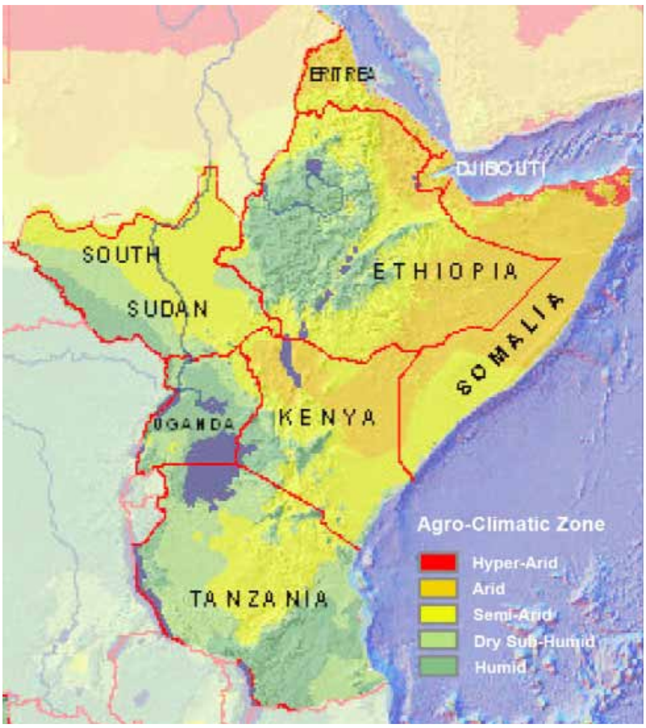


Figure 3.1 Drylands in Eastern Africa.

A classification of drylands based on level of aridity does not fully account for the variation in agro-ecological conditions in the drylands of the Eastern African region for two reasons. First, the regions' significant topographic variation creates drylands from sea level to 2500m and above which causes significant thermo-climatic variation within arid, semi-arid and sub-humid systems. Second, the equatorial drylands of Eastern Africa have a bimodal rainfall pattern, with long rains from March to May and short rains from October to December. The exact distribution of areas with uni-modal and bimodal rainfall in the Eastern African region is not well known, due to the general scarcity of rainfall stations in the drylands. Analysis of the length of green vegetation from long term satellite imagery allowed [1] to assess the length of the growing season and localize areas with one and two growing seasons (Figure 3.2). The analysis demonstrated that the bimodal pattern of vegetation greenness extends to the north to northern Ethiopia and Somalia. South of the equator the two seasons merge into a single green season near the Kenya-Tanzania border.

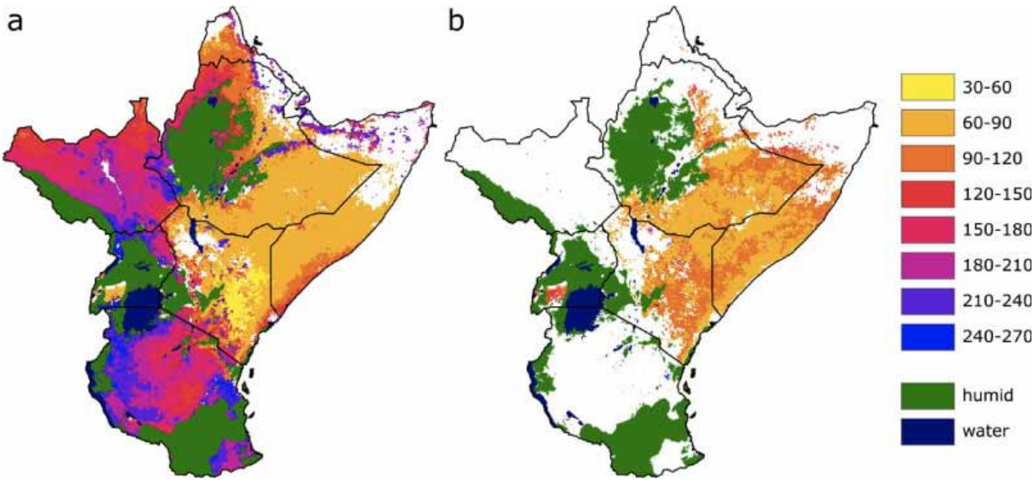


Figure 3.2 Length of the growing season (days) for Eastern Africa based on 30 years of NOAA AVHRR data for the first (a) and second (b) season.

The above approaches classify African drylands according to long term average agro-ecological conditions. Weather conditions vary from year to year leading to variation in length of the growing season between years. Vrieling et al., [1] also estimated the variability of seasonal duration as expressed by its coefficient of variation (c.v.). Figure 3.3 reveals that the drylands of Eastern Africa have a very high inter-annual variability in length of growing season, particularly for the areas with bimodal distributions. Another region with a very high c.v. for length of the season is the Kenyan Tanzanian cross-border part of Maasai land. Noteworthy is that the remote sensing imagery reveals that the drylands in Eastern Africa has patches with inter-annual variability in seasonal length greater than 0.20 (Figure 3.3), which is higher than the variability in the Sahel with a unimodal rainfall distribution[1].

The arid lands have sparse vegetation used almost exclusively for pastoral grazing. The semi-arid and the dry sub-humid lands are characterized by either one or two rainy seasons with mean annual precipitation (MAP) ranging from 500–750mm per year. Agro-pastoral and mixed farming systems based on drought-tolerant short to medium duration cereals, sorghum and finger or pearl millet and pulses are common and maize is grown for its potential and popularity as a food but often fails during drier years. Other food crops include cassava, and sweet potatoes while tobacco, cotton and sunflower are important cash crops. *Mangifera indica* (Mango) is produced where enough rainfall is received or where irrigation is available, while tree species such as *Vitex payos* and *Balanites aegyptiaca* are harvested for their edible leaves and fruits.

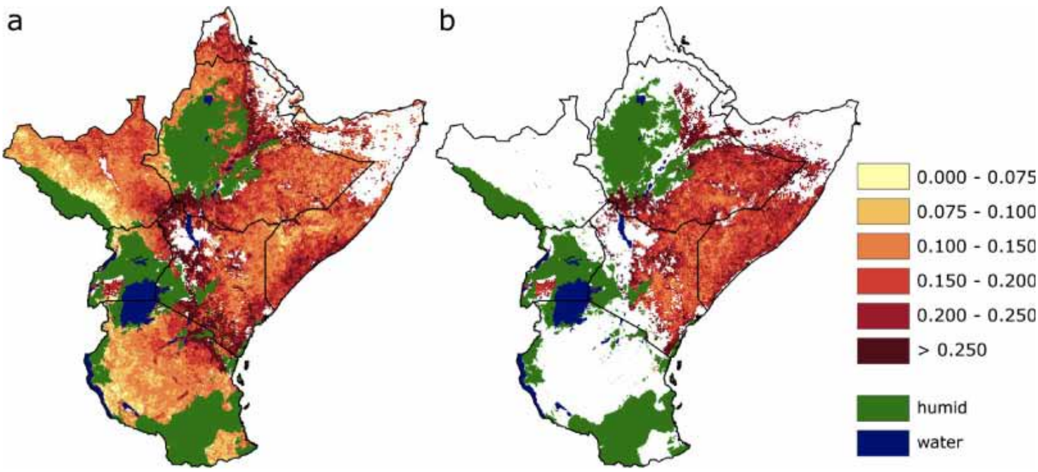


Figure 3.3 Coefficient of variation (c.v.) of length of the growing season for Eastern Africa based on 30 years of NOAA AVHRR data for the first (a) and second (b) season. Source: [1]

Source: [1]

3.2 The water cycle

Water is the most critical limiting resource for plant growth in drylands. In Eastern Africa, mean annual precipitation (MAP) decreases when moving inland from the coast and increases with elevation. People use two fractions of the rainfall: the first is the blue water, which is stored in water bodies (streams, rivers, ponds and lakes) and groundwater; the second is the green water which is transpired by plants through their stomata to allow the gas exchange that permits photosynthesis and the production of sugars, the energy carriers supporting life on earth. In drylands much of the rainwater is evaporated directly from the substrate without being converted to green or blue water. The Green Water Use Efficiency (GWUE) is the percentage of rainwater used for transpiration and primary production. The GWUE in African crop- and rangelands of 2% and 16% (De Leeuw, unpublished) is lower than the GWUE of up to 50% achieved under similar conditions in the USA with better soil evaporation control.

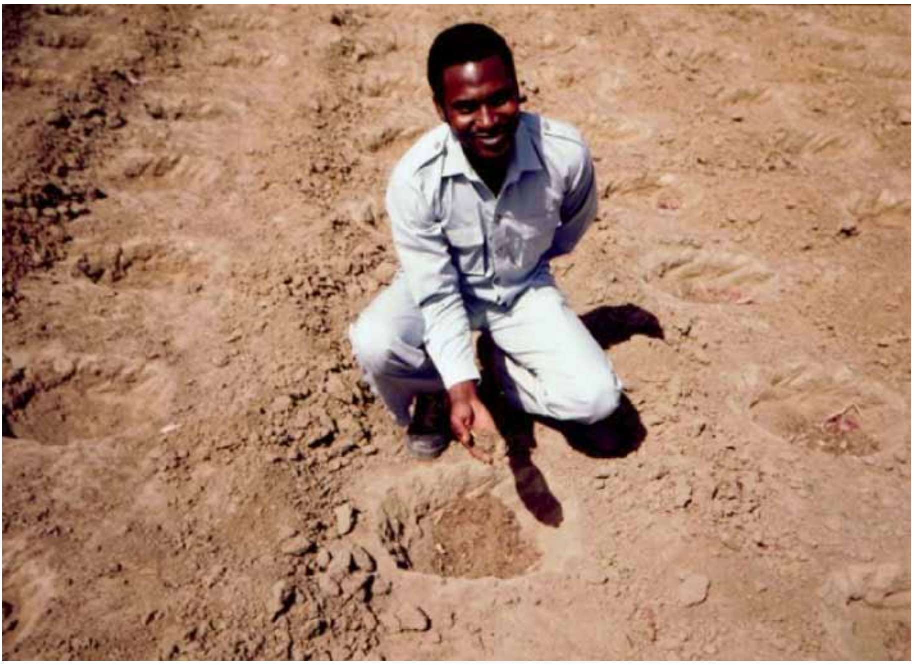


Figure 3.4 Planting pits in Burkina Faso, Photo Critchley.

These low GWUEs imply that there are ways to increase the green water use efficiency and primary production through interventions that increase the proportion of green water while promoting the infiltration and decrease evaporation and runoff. These include techniques that promote the in-situ infiltration of a greater proportion of the rainwater into the soil, for example through zai pits (Figure 3.4), terraces, ditches and minimum tillage techniques. In pastoral and agro-pastoral areas, retaining good vegetative ground cover, including grass, reduces evaporation and increases infiltration. A second range of water harvesting techniques, which store water for later use for domestic and agricultural purposes include ponds, check dams and weirs, and sand/sub-surface dams. Agricultural water harvesting techniques are most effective when combined with improvements in soil fertility. When water stress is reduced, the response of growing crops depends upon nutrient levels in the soil. Conservation agriculture is a strategy that combines a variety of techniques including minimum tillage, crop rotation, mulching and micro-dosing so as to increase soil moisture and nutrient availability. In recent years, ICRAF has improved conservation agriculture by incorporating tree species into farming systems. The species include *Faidherbia albida*, *Calliandra calothyrsus, Combretum glutinosum* and *Gryricidia sepium*.

Figure 3.5 Evergreen agriculture with *Faidherbia albida* in Zambia, Photo Mei Xie.

This new concept dubbed "Evergreen Agriculture" increases and stabilizes production as well as improves resilience of the entire farming system [2, 3]. In the example in Figure 3.5, the conservation agriculture plot was tilled with a hand hoe and planted with *Faidherbia albida* at a spacing of 10m x 10m. The average maize yield was 5,000 kg/ha and carbon increased by 4% of over seven years.

3.3 People in Eastern Africa drylands

The total population of the Eastern African region (estimate for 2013) stands at 250.3 million people (Table 3.1). Ethiopia has the largest population with 94 million people while Djibouti is the least populated country. Nation-wide population densities vary from 16.3 people per km^2 in South Sudan to 176.4 in Uganda.

Table 3.1 Population, population densities and fraction of crop and non-cropland for the countries of Eastern Africa

Country	Population million	Population density N/ km^2	Cropland %	Non cropland %
Djibouti	0.79	34.3	0.09	99.91
Ethiopia	93.88	93.9	14.20	85.80
Eritrea	6.23	61.7	5.88	94.12
Somalia	10.25	16.3	1.77	98.23
Kenya	44.04	77.4	10.60	89.40
S. Sudan	11.09	17.2	--	--
Uganda	34.76	176.4	37.05	62.95
Tanzania	49.26	55.6	14.04	85.96
Total	250.30			

There is a highly significant positive relation between human population density and the fraction of the lands in use as croplands (Figure 3.6). Remarkable also is that the vast majority of land is not used as croplands, a phenomenon that holds for all countries. A large proportion of this land is located in the drylands and consists of rangelands used for extensive livestock keeping.

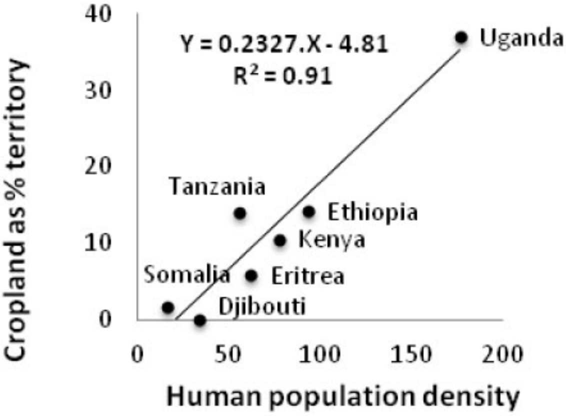


Figure 3.6. Relation between human population density and fraction of the national territory used as cropland for seven Eastern Africa countries (South Sudan excluded for lack of land use data).

At sub-national level population densities change from high potential highlands and near metropolitan areas with over 800 people per km^2 to less than 30 people per km^2 over most of the region in lowland and dryland areas (Figure 3.7).

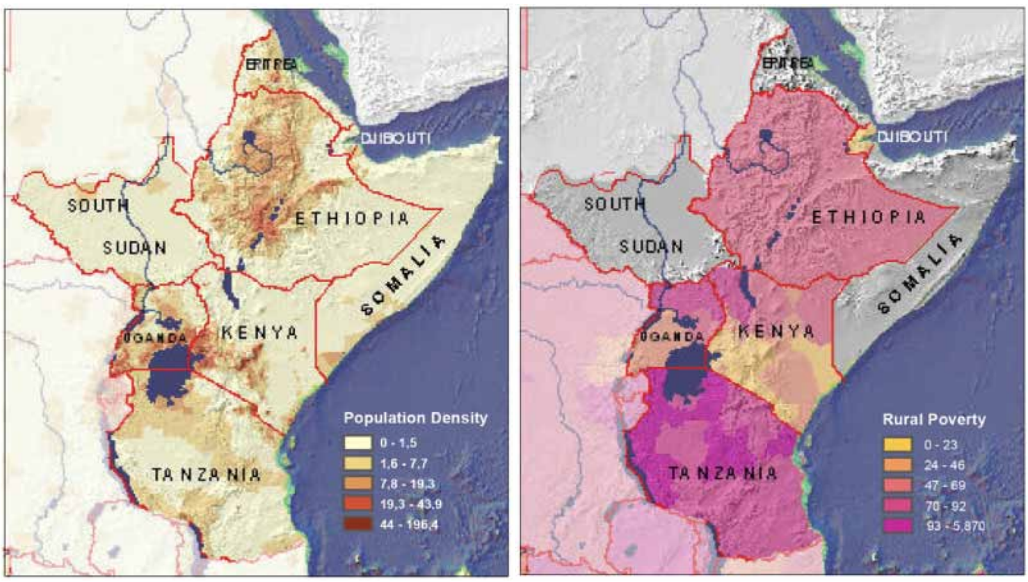


Figure 3.7 Left: Human population densities, **Right:** Percentage of the population living below the poverty line of 1.25 US$/day. Source: Harvest Choice.

3.4 Poverty and inequality

Poverty is widespread in the drylands of Eastern Africa. Poverty has been mapped at sub-national level (Figure 3.7) for several but not all countries in the region. The map shows higher than national average levels of poverty in the drylands of northern Kenya and northern Uganda. Tanzania as a country has a poverty level of 80%, similar to Turkana district in northwest Kenya.

Poverty assessments are often based on measurable sources of income. However, income as a sole measure of poverty has been criticized as inadequate since it fails to evaluate other benefits from nature that are not accounted for including assets such as trees on farm and livestock that are important but frequently undervalued components of the wealth of people in drylands [4]. Income poverty may be transitory or chronic. Transitory poverty is when shocks affect households but leave them with the ability to recover either on their own or aided through traditional or formal safety nets, including informal and formal insurance, communal pooling and disaster assistance. Chronic poverty, on the other hand, is when households are locked into poverty in the long-term, and are unable to escape without external assistance.

High levels of poverty are not necessarily related to a lack of opportunity to secure livelihoods in the drylands, but rather to the isolation of dryland communities from means of investment and earning. Often, while the better-watered parts of countries have developed, the drylands have been left with historical levels of poverty and destitution. It has always been a challenge for the communities living in the drylands to adapt to the severe ecological challenges that they encounter, but with proper economic links to areas where there is a demand for the products of the drylands, there should be better potential to improve economic conditions in the drylands.

The fact that huge dryland areas are left as sinks of poverty cast doubt on the adequacy of the policies of donors and national governments, and whether development and relief efforts have been enough to genuinely transform poor economies or serve to perpetuate poverty traps. There has been significant investment in relief in the dry areas of Eastern Africa. A total of 13.3 million people needed assistance in Ethiopia, Kenya, Somalia and Djibouti during 2011 as a result of what aid agencies said was the worst drought in the region in six decades. This was the culmination of a decade during which relief spending had increased greatly. During this time, spending on Disaster Prevention and Preparedness (which includes the effects of drought) was very low (Table 3.2).

Table 3.2 Average Annual Donor Spending on Disaster Prevention and Preparedness (AADS-DPP) before the 2011 Horn of Africa drought. Source [5] [6]

AADS-DPP	Kenya	Ethiopia	Somalia
In million US$	2.22	3.3	0.7
As % of humanitarian aid	0.91	0.59	0.19
Per person 2011 drought (US$)	0.59	0.69	0.19
As % of ODA	1.4	0.9	0.3

Recently, priorities have begun to change, with an increased emphasis on development investment in the expectation of reducing disasters. The international community announced a new partnership to strengthen resilience against disasters in the Horn of Africa [7]. Centres of the Consultative Group on International Agricultural Research (CGIAR), under the coordination of the International Livestock Research Institute (ILRI), have joined with Food and Agriculture Organization of the United Nations (FAO) to support the partnership. These welcome developments highlight a determination to fight poverty in drylands through measures that increase resilience, and put proper emphasis on development investment to bring about transformation and a shift from dependence on relief spending. On the same note, a summit was held in Nairobi on 9th September 2011 to explore how to build drought resilience and sustainable livelihoods in the Horn of Africa.

However, there is also considerable inequity in the distribution of wealth and assets like land and livestock across and within communities. Land tenure systems differ between regions and countries, with state-owned land with user rights managed at village level in Ethiopia and Tanzania and a mixture of government trust land and communal or individually-owned lands in Kenya. In areas where land has been privatized, land ownership is typically unequal with significant impacts on income and other benefits from agriculture and other ecosystem services. In communally-owned lands, which are common in pastoral areas, it is the distribution of livestock that matters. The distribution of livestock across households is typically skewed with Gini coefficients of around 0.50 or higher [5], corresponding to a situation where 20% of the livestock owners holding 60% to 80% of all livestock. These inequity statistics exclude pastoral households who have lost and have been left without livestock and their number amounts to 50% of the population of Turkana district in Kenya. The wealthier livestock owners are thus at an advantage over the poor or livestock-less in reaping the benefits from the grazing land common pool resource.

Livestock has traditionally been the asset-buffering livelihood in much of the drylands. Pastoralists are highly skilled in maintaining optimum herd sizes while moving around the landscape to take advantage of grazing and water during different seasons. This requires not only unfettered access to traditional rangeland, but also adequate links with markets where surplus stock can be sold and food purchased. Pastoralists are dependent upon selling their animals to buy the cereals, oil, tea, sugar and other commodities that they carry with them. Unfortunately insecurity, cattle rustling, poor infrastructure and poorly functioning markets disconnect pastoralists from the economic opportunities that markets provide Droughts severely exacerbate the situation. Severe droughts kill animals leading to a loss of livestock, which is the pastoralists' main asset. When assets are lost people are prone to fall into poverty traps. Poor households that lose their herds during drought increasingly fail to rebuild their herds, facing a 'poverty trap' with too few animals to sustain a decent living [7] as illustrated in the case of Mohammed in Ethiopia presented in Box 3.1.

Box 3.1 Drought pushes Mohammed into chronic poverty in Ethiopia Source: [8]

> Mohammed, 55 and illiterate, who resides in the Bati district of South Wollo Zone (Ethiopia) and heads a household of nine has been chronically food insecure for more than 10 years when he lost his only ox due to drought. He sold the animal to buy food at the time and has not been able to acquire another. Currently, Mohammed holds one hectare of farmland without grazing land. Since he owns no ox, he has been leasing out the land for share-cropping on a 50/50 sharing arrangement, an arrangement that leaves the family with too little food and income to survive. Mohammed and his family members are thus engaged in various types of daily labour activities for cash and food, and the household is a regular recipient of food aid. Mohammed asserts, ‘‘oxen is the crucial productive asset that would liberate me from this insecurity”.

Similarly poor people in crop-based systems may be forced to sell their assets including valuable possessions and even their land to overcome adverse periods, which spiral them into poverty. On the other hand, households that manage to accumulate assets or who adopt new technologies or favourable shifts in their terms of trade will grow their way out of poverty. Among the very poor populations this growth could take some time, but movement nonetheless can proceed steadily under certain enabling conditions [9].

3.5 Livelihoods, natural hazards, vulnerability and resilience

Poverty indicators focusing on income do not capture human well-being fully. This is because there are more factors that determine the ability of people to make a living. The livelihood approach [10] groups these factors under five assets that make up a livelihood. These include first the human capital representing the skills, knowledge, good health and the ability to work that together enable people to pursue different livelihood strategies and achieve their livelihood objectives. Second the social capital such as networks and relationships based on trust, reciprocity and exchanges. Third, the natural capital such as natural resource stocks from which resource flows and services useful for livelihoods are derived. Fourth is the physical capital comprising the basic infrastructure and producer goods needed to support people’s livelihood. Fifth is the financial capital denoting the financial resources that people use to achieve their livelihoods such as available stocks, which can be held in several forms such as cash, bank deposits, liquid assets such as livestock, or resources obtained through credit-providing institutions and regular inflows of money, including earned income, pensions, other transfers from the state, and remittances.

The livelihood approach has found wide acclaim and application because it brings together these various components that determine human well-being. It has been used for example in analysing the asset base that underlies the well-being of people and to explore the impacts of interventions on this asset base. The livelihood approach can also be used to assess the impacts of natural hazards on human well-being. Figure 3.8 portrays the livelihood as a buffer between the risks imposed by natural hazards and human well-being.

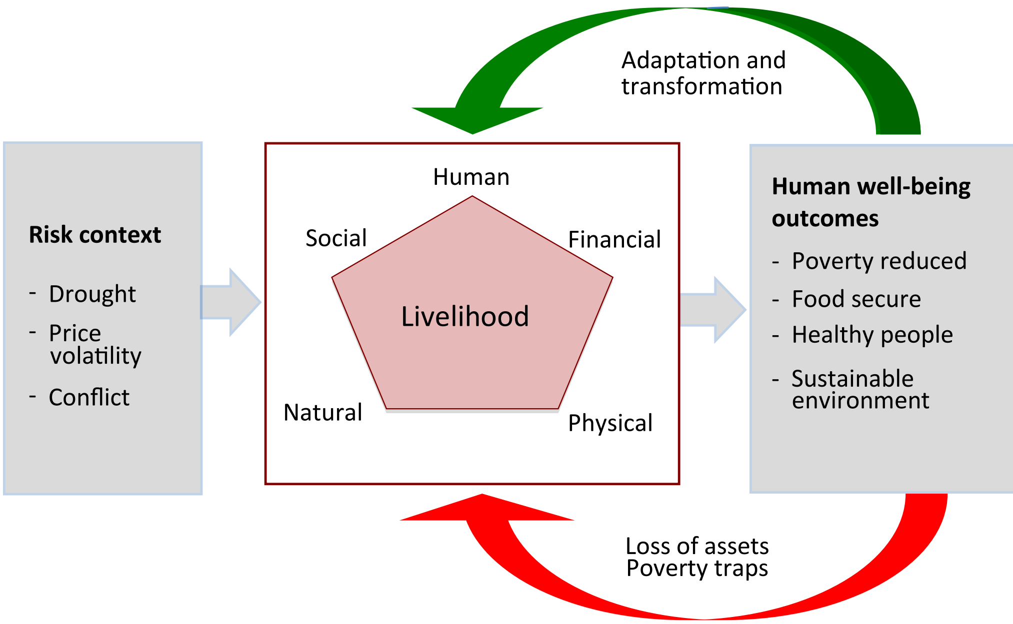


Figure 3.8 Livelihoods buffering households against natural hazards in drylands with a negative feedback loop of asset loss and a positive feedback loop of adaptation and transformative change weakening respectively strengthening livelihoods.

A livelihood is classified as sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in future, while not undermining the natural resource base [10]. The livelihoods in the drylands of Eastern Africa are affected by a number of natural hazards. Repetitive drought is the most prominent natural hazard; others include floods and animal and human diseases triggered by these. Other factors such as conflict, weak institutions and inadequate policies are not natural hazards, but factors that worsen the impacts of these natural hazards. People living in drylands are thus facing the risks of losing their assets from the numerous natural hazards whose impacts are worsened by other underlying issues as mentioned earlier. As such it is important to understand the concepts of vulnerability and resilience and how they relate to the way livelihoods and human well-being outcomes are affected by impacts of natural hazards.

Vulnerability is an undesirable condition referring to the characteristics and circumstances of a community, system or asset that makes it susceptible to the damaging effect of the hazard. Vulnerability is often the result of extreme poverty, especially where poor people have limited options on how to sustain their livelihoods, and exposure to hazards compromises their primary livelihood. A typical example from the drylands would be where long-term drought has begun to push food prices up and is affecting the condition of pastoralists' livestock or causing death of the animals. If the pastoralists find themselves in a position where it is difficult to sell excess stock to buy food and guard against future hunger, they will find themselves in a deteriorating situation. Similarly, vulnerability increases when there is reduction in transfer of resources such as through remittances and gifts as a result of diminished assets.

Resilience is a desirable condition, often simply considered as the converse of vulnerability, where people have the means to protect themselves from, or survive hazards. Complete protection from drought, flood and other eco-physical factors is impossible (it either rains or it does not). Communities in drylands have become very good at surviving hazards, and their resilience often allows them to survive shocks, well prepared to continue with their ways of life. Development efforts to increase resilience should aim for solutions that lead to continued progress, rather than basic coping mechanisms that help people but leave them in poverty traps [11].

The concept of resilience has various connotations, which revolve around how a system responds to disturbance. *Instant responses* include the capacity of a system to absorb a shock and to recover and regain pre-disturbance conditions. Immediate responses suffice in case of smaller disturbances which people are familiar with and for which they have developed mechanisms to cope. However, instant responses may not suffice in case of increased vulnerability or larger and unprecedented hazards. Yet, people and societies have the ability to learn from past experience, and decide to adapt or even to transform the system to respond more effectively to future disturbance. Adaptation and transformative resilience are *delayed responses* because they require time for social change. Bene et al. [12] thus propose three system-level responses included in the resilience concept: the ability to respond immediately, which they call *resistance,* in a period of small disturbance, and change of the system to acquire greater resistance; *adaptation* in times of greater disturbance; and *transformability* when disturbances become untenable.

Building resilience depends upon maximizing the value of the five "capitals" identified under the livelihoods approach: human, financial, natural, physical and social. In this way, people develop options that allow them to diversify their livelihoods, thus making them less vulnerable to certain shocks. Building resilience is an exercise that requires a holistic approach, recognizing the economic, environmental and social elements of people's development. Trees can contribute in many ways to this endeavour. Trees as natural capital for example, regulate water and soil erosion, provide browse material, pods and bark for livestock and fruits and leaves for human consumption during drought. Trees also contribute to physical capital, particularly as building materials, but also in other roles in the landscape such as windbreaks (often vital for controlling soil erosion) and in water harvesting structures. Trees have an important role to play in building social capital. Boundary trees define landholdings, and systems of tree tenure determine who benefits from trees. An increase in trees, along with the development of markets and value chains will link dryland communities to profitable urban centres where tree products are needed. For example, income from forests and trees on farms can make a significant contribution to rural households and their food security.

The collection, processing and sale of forest products (or activities involving non-consumptive use of forests such as ecotourism) are often among the few income-generating opportunities available in these areas. Women play an important role in the processing of tree and forest products. The creation of small or medium-sized forest-based enterprises can help secure better market access and share, or add value to harvested products. Many small-scale enterprises are based on non-wood forest products (NWFPs) such as gums and resins and are good sources of income during drought. They are particularly important in arid and semi-arid areas where agricultural production is more vulnerable to external threats such as drought or extreme weather events. Charcoal production as a coping mechanism increases during drought when no other sources of income or food are available as illustrated in the case of Veronicah in northern Kenya presented in Box 3.2 and has potential to be made sustainable as discussed in a later section on wood fuel. Equally important and widespread is the collection of firewood for income.

Box 3.2 Charcoal burning as a coping mechanism to generate income during drought

> "We either burn charcoal or die of starvation. Manual work is no longer available, as those who used to employ us to do house chores are also affected. We [charcoal sellers] are considered a nuisance, enemies to the environment, and our charcoal is often confiscated. But we deserve to be assisted rather than condemned." The Guardian 20 July 2011.

Human capital is needed to capitalize on the value of trees. At present, people destroy trees for immediate benefits even when they are aware of future impacts, possibly due to lack of other options for income generation. Farmer-managed natural regeneration (FMNR) in parts of Africa clearly demonstrates the benefits of nurturing trees. With the proper development of relevant human capital, people will be able to exploit trees to a much greater extent, and develop new and diversified livelihoods that are much more resilient to the hazards of the drylands.

However, trees may not be considered by communities as direct building blocks of resilience where for example, forest (7 scores) or natural resource management (83 scores) are rated quite low compared to peace and security (792 scores) and water (598 scores) as found through Community Based Resilience Analysis (CoBRA) by United Nations Development Programme (UNDP)'s Drylands Development Centre in Kenya and Uganda (UNDP, forthcoming). CoBRA help the drought/disaster affected communities better engage in the process of defining and identifying "good disaster risk reduction (DRR) practices" in a meaningful and systematic fashion, in recognition of the current absence of shared understanding of "good", "best" and "success" and indicators/comparable data to measure tangible long-term impacts of the DRR interventions. The CoBRA assessment also assists the communities in internalizing the term "resilience" in their specific contexts.

This chapter introduced the drylands of Eastern Africa and developed a narrative on the importance of strengthening resilience of the livelihoods of people living in this region. Trees may contribute to enhancing this resilience, but their possible role is not clear. Shedding clarity on the role of trees requires insight into the multiple benefits that trees provide. The next chapter argues that an ecosystem service perspective is an appropriate approach to assess the multiple resilience enhancing benefits from trees.

Chapter 4: Conceptual framework on trees and resilience

Uriel Safriel, Mary Njenga and Jan de Leeuw

Perspectives on resilience

Resilience could be approached from several perspectives. At first sight a tree-based perspective focusing on the products that trees provide appears logical. However, many of the benefits that people derive from trees are indirect, for example the positive effects of trees on the production of crops and livestock, through regulation of the cycles of water, nutrients and carbon, which would not be appreciated when focusing on the goods and direct benefits that people derive from trees. We have thus chosen to review the resilience provided by trees from the broader ecosystem services perspective and its contribution to land users' livelihoods.

Land-based livelihoods, biological productivity, and drylands

Farmers, pastoralists and agro-partoralists from the drylands of Eastern Africa depend daily on the land's biological productivity, one that generates products of economic value such as food, fibre, and other products. These land uses, and especially those that generate food, are of global significance – currently two billion food-producing land users each day feed themselves and the other five billion human inhabitants of our planet.

Food production depends on land productivity, which is expressed in plant productivity, and this is through the plants' process of primary production – primary, since it is derived from nature's raw materials converted by photosynthesis into organic matter. This process requires optimal ambient conditions such as temperature and resources – solar energy, minerals and water. All these combined are a must, but the process is limited by the factor that is in short supply. In drylands, which comprise about 40% of the global land, water is the overriding limiting factor of primary productivity. These lands experience climatic conditions under which soil moisture is low since water loss through evaporation and plant transpiration (evapotranspiration) is at least around 1.5 times higher than rainfall. As a result, the natural biological productivity of drylands is lower than all other terrestrial ecosystems (except those of the polar areas, in which productivity is even lower).

In spite of this constraint, the drylands host 37% of the global human population, 44% of the world's food production system and 50% of the world's livestock[1]. Yet, the land productivity-based livelihoods in the drylands are vulnerable, and many of the world's

[1] http://www.unccd.int/Lists/SiteDocumentLibrary/WDCD/DLDD%20Facts.pdf

poor are among these land users, especially in the African drylands, Eastern Africa countries included (see chapter 3 on the drylands of Eastern Africa). The reason is that in drylands productivity is constrained not only by the low water availability, but also by high variability and low predictability of water provision. The extreme expression of these constraints is drought, whose intensity and frequency in drylands are currently on the rise – an ominous attribute of global climate change.

Enhancing the resilience of land users and of land productivity in drylands

In spite of being exposed to the relatively unfavourable dryland climate, the natural biological productivity of the drylands as well as its users, the dryland people and communities have, through the millennia, acquired resilience to these conditions, which enable both land and human well-being to regularly recover following droughts and other nature-induced shocks like floods and fires. However, the relatively recent high human population growth rate and increasing frequencies and intensities of droughts in the drylands are undermining the resilience of both land and people. This eroded resilience is a result of a vicious cycle of land users driven to reduce the capacity of the land that supports them, which further exacerbates their well-being.

In this document we highlight the potential of agroforestry in enhancing the resilience of the drylands' biological productivity, consequently improving the resilience of the traditional dryland livelihoods. We do this by elucidating the qualities and attributes of trees within the drylands' natural and human-induced constraints.

Ecosystems and their services

It is illuminating to express the dependence of people on the land's biological productivity by adopting the natural capital and ecosystem approach framework and terminology. This framework has been developed by the Convention on Biological Diversity (CBD), the Millennium Ecosystem Assessment (MA), the Natural Capital project (Integrated Evaluation of Environmental Services and Tradeoffs – InVEST, http://www.naturalcapitalproject.org) and by the more recent assessments such as the UK-National Ecosystems Assessment (UK-NEA). Under this scheme, lands that are natural or managed as croplands or rangelands through the farming, pastoral or agro-pastoral systems are considered "*ecosystems*" – natural ones transformed to cropland or rangeland ecosystems.

An area is qualified as an ecosystem provided that it supports plants and other organisms that perform basic ecological functions – photosynthesis (by plants), and nutrient cycling (by decomposing micro- and macro-organisms). These functions and others are performed through interactions between the assemblage of species that reside in the ecosystem (its "biological diversity" or "*biodiversity*"), and between it and the non-living components of the ecosystem (such as soil and climate). Those functions that support human well-being are the "*ecosystem services*" – benefits people derive from ecosystems. Thus, the biological products of economic value such as food products produced by an agro-ecosystem are the products of the *provisioning service* of this ecosystem.

In a wheat crop agro-ecosystem, the product is the wheat seed, produced by the wheat plant. But four ecological functions enable the wheat plant to do that – the agro-biodiversity, the photosynthesis (executed by the wheat plant leaves) and soil-water and nutrient cycling. The latter is carried out by macro- and micro-species that decompose dead organic material to soil mineral nutrients. These nutrients are absorbed by the roots to serve as raw material in the plant's productivity process. It should be noted that the wheat seed is harvested and consumed or traded on the market, while the wheat plant itself (an agro-biodiversity component) and the soil biodiversity component of the agro-ecosystem, are not harvested. Rather, these biodiversity components constitute the agro-ecosystem's *natural capital*, one that generates the services and their products of economic value. Hence, a sustainable use of services is one that does not impair the potential of the ecosystem's natural capital, i.e., its biodiversity, to generate ecosystem services used and exploited by the land user (Figure 4.1). Thus, these four ecosystem functions or "*supporting services*" support the food provisioning service of generating the wheat seeds.

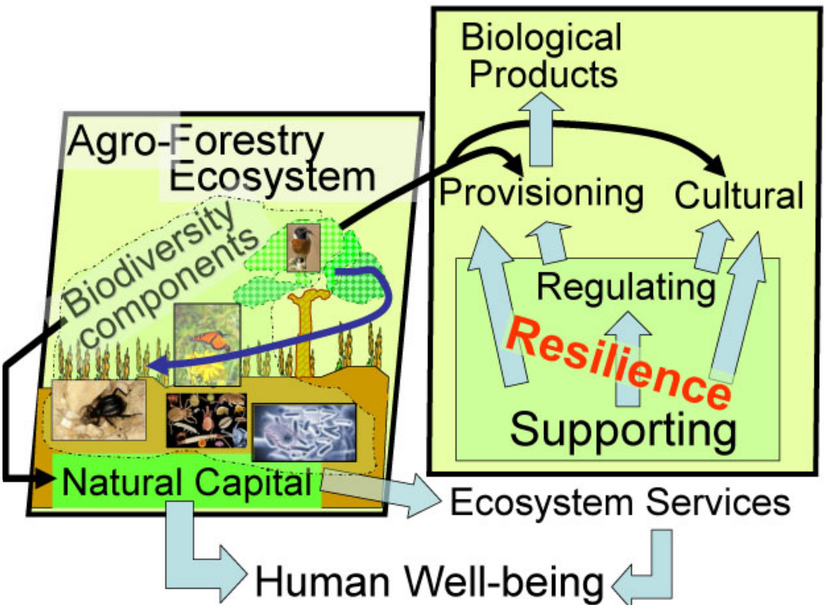


Figure 4.1 **Left:** Structure and function of an agroforestry ecosystem and **Right:** the ecosystem services provided by the tree component of the system.

The **biodiversity** components of this ecosystem (the tree, the crop species, soil biota, pollinators and pest-controlling insectivorous birds) comprise the **natural capital** of the system; this natural capital generated the ecosystem services that operate within the system and lead to the **biological product**, the cultivated crop.

The tree component of the system may generate added **provisioning** services, and also generate **cultural** services (the two black arrows exiting the ecosystem) but the major contribution of the tree to the system, which is critical to the crop (internal blue arrow in the ecosystem box) – the **supporting** and especially the **regulating** services that confer **resilience** to the whole agroforestry ecosystem (green box on the right); to conclude, both the natural capital and the ecosystem services of the system contribute to **human well-being** (bottom).

Sustainability and resilience in dryland agro-ecosystems

The ecological functions, photosynthesis and decomposition, which generate the supporting services of agro-ecosystems, primary production and nutrient cycling, respectively, are water-dependent. But in drylands they are also water-limited. Moreover, in drylands the water supply is temporally variable, interrupted by spells of droughts. Thus, while human well-being requires a stable supply of biological products, this dryland's climatic variability impairs the provision of the supporting and hence also the provisioning services, making the livelihood of dryland land users highly vulnerable.

This vulnerability often drives land users to over-use the land, which has an impact on soil properties and the agro-ecosystem biodiversity, i.e., the system's natural capital, what impairs its potential to generate the supporting and the provisioning ecosystem services once the drought ends. Thus, land use in the dryland is always at risk of being non-sustainable – impairing the potential of the land's natural capital to generate the services required for maintaining the land users' well-being.

Hence, the nature of drylands requires implementing measures that would increase the resilience of the drylands' natural capital to maintain its potential for *sustainably* generating ecosystem services. This would make land users resilient to the drylands' vagaries of water availability and would promote sustainable well-being. It is here suggested that this ecological and social resilience can be conferred by transforming agro-ecosystems to agroforestry ecosystems by introducing and promoting the tree life-form and biodiversity component to dryland agro-ecosystems.

Trees – natural capital conferring ecological and social resilience in drylands

In its natural state trees dominated most of the global land in the tropical, temperate and boreal latitudes and climates, including the sub-humid and semi-arid drylands while trees are more scattered in arid to hyper-arid lands. However, there is a relatively high diversity of dryland-adapted trees in the drylands of Eurasia, the Americas and Africa. As all dryland plants, dryland trees too are water-limited, but the asset of trees in dryland is their high resilience to water scarcity, as compared to other plants.

Trees' regulating services

Having deep and extensive root systems, a wide canopy and complex and diverse architectural structure, dryland trees constitute a crucial dryland natural capital – a biodiversity component that is engaged in provision of a bundle of ecosystem services classified as *regulating services*, the most important of which and tightly linked are the water regulation and soil conservation services. Cascading through the canopy, branches and leaves of the tree, rather than breaking the soil aggregates once they land on the soil surface, raindrops gently land on the soil, penetrating it slowly, either to become deep soil moisture, well protected from evaporation, or even infiltrate to aquifers. Other plants, including crop plants, benefit from this soil and groundwater enrichment. Furthermore, surface runoff is reduced, and together with the effect of the root system, soil erosion is prevented. In addition, the canopy protects soil moisture from evaporation (Section 6.4.1). Of course, trees use water and transpire water, but dryland trees physiology, morphology and phenology are well-adapted to water conservation.

Trees' supporting services

Like all other plants trees are engaged in providing the nutrient cycling supporting service by absorbing mineral nutrients from the soil and later returning them to soil in the form of organic matter of the dead leaves that become litter. However, due to their deep roots, trees intensify nutrient cycling by reaching the nutrients of the deeper soil horizons, to be later released and enrich the topsoil layers with the fall of litter and dead wood. Leguminous trees provide another supporting service, that of fixing atmospheric nitrogen thus maintaining the nitrogenous component of the nutrient cycle. This is carried out through symbiosis with another biodiversity component, that of nitrogen-fixing rhizobium bacteria associated with the expansive root systems of trees, including many of the dryland tree species.

Trees' provisioning services

Because trees are better adapted to water scarcity than other crop and forage plants, this component of biodiversity added to the agro-ecosystem transforms it to an agroforestry ecosystem that is highly resilient to the dryland climatic shocks. This is because trees not only excel in providing regulating services, but also generate a diverse suite of provisioning services (products of economic value – timber, wood fuel, fodder, food and medicinal products), most of which can be sustained during drought years too. The resilience these products confer on the land users livelihood is two-faceted: in "good" years it increases their income on top of that derived from the cultivated crops or livestock; such that surplus would be used in the drought years, in which income will still be derived from the tree products. The two tracks combined therefore enable land users to maintain their well-being during the drought years, with no incentive to overuse their land in drought years, use that would have put at risk their lands' natural capital.

Trees' cultural services

Trees, more than other plant biodiversity components, also generate cultural services, sometimes as individuals, and more often their aggregation in groves, woodlots, etc, and often when comprising islands of greenery in otherwise bleak landscapes. These cultural services have a potential to be translated into recreation and tourism opportunities, which are also sustained during drought years, when the contrast between trees and other cropland or rangeland vegetation may dramatically increase. Thus, there are many and diverse ways in which trees directly promote land users' income, hence building resilience to the natural attributes of drylands – the inherently low land productivity, driven by variable and erratic water availability.

Importance of regulating and supporting services in tree-based resilience

Among the four types of ecosystem services, people derive the more tangible and direct benefits from provisioning and cultural services. It would be short-sighted however to restrict our perspective to the resilience provided by trees to these two categories of ecosystem services. The reason for this is that the delivery of both the provisioning and cultural services depends on the sustained supply of the regulating services. These three types of services combined depend on the sustained delivery of supporting services. This is the case for all ecosystems, but particularly in the drylands where the provision of the supporting service is at risk of reduction and collapse, due to the dependence of primary productivity and nutrient cycling on the low and highly variable water availability. The advantage of trees over dryland crop species is in their high water use efficiency which make trees a resilient natural dryland capital: trees' supporting service is sustained and thus it also sustains the provision of the regulating services, that in turn sustain the yield of the tree-generated provisioning and cultural services. Thus, ultimately it is the resilience of the provision of supporting and regulating services, which confers direct and resilient benefits to people in dryland agroforestry systems (Figure 4.1).

Dryland woodlands, afforested forests and agroforestry ecosystems

Dryland land users often capitalize on the services provided by woodland and afforested forests, mainly for their timber, or non-timber forest products, and recently also their carbon sequestration service that can generate income under the carbon trading mechanisms. The provision of these services from forest ecosystems in non-drylands is more intense and profitable than in the dryland woodland and forest systems. Nevertheless, forests and woodlands contribute to human well-being also in drylands, where land users often badly need to improve their well-being. Trees also occur in non-forest ecosystems, and introducing cultivation to any non-forest ecosystem that includes trees or introducing trees into crop-cultivation ecosystems is beneficial. This is not only due to products that the trees provide and are of economic value, but also because trees in an agroforestry ecosystem are beneficial for crop production in that system, as explained below.

The resilience of the agroforestry ecosystem

Transforming a dryland agro-ecosystem into a dryland agroforestry ecosystem by introducing trees to the agro-ecosystem, not only increases the suite of ecosystem services, but may also increase water availability for the crop plants. This is through the water regulating service provided by the trees, which under some circumstances would improve the soil moisture regime in the transformed ecosystem such that more soil moisture becomes available to the crop plants (Section 6.3.2). Furthermore, the trees provide a habitat for pollinators (bees, butterflies, birds) and pest predators (birds, bats), and are therefore instrumental in providing the pollination and pest regulation services to crops, hence promoting the crop's provisioning services.

To conclude, the sustained provision of supporting and regulating services of the trees in an agroforestry ecosystem confer resilience to this ecosystem type, including to the provision of the “agro” crops’ products. This ecologically-driven resilience contributes to the human well-being of the practitioners of the agroforestry livelihood.

The resilience of the agroforestry livelihood

People in drylands cope with the shocks created by drought and other natural hazards in multiple ways. The livelihood approach [10] groups these factors under five assets that make up a livelihood as discussed earlier.

The natural capital of the agroforestry ecosystem is of a high importance in enhancing resilience. Yet, achieving inclusive resilience at household level also requires the provision of the other forms of capital, and their abundance provides instant resilience to hazards. However, the natural capital and associated ecosystem services that trees provide contribute to all other forms of capital required for promoting resilience. Trees contribute to: the *financial capital* (their provisioning services - selling timber and other NTFPs); the *physical capital* (timber used as house building material): the *social capital* (i.e. the cultural services provided by trees and tree groves, etc.); and the *human capital* (the human health and disease regulation services to which trees often significantly contribute). Further, given that besides contributing to all other capital assets, trees themselves are a component of biodiversity hence a major natural capital, then the transformation from agricultural livelihood to agroforestry livelihood constitute both *adaptation* and *transformability* responses of land users to the drylands’ inherent low productivity and high occurrence of shocks. All these combined suggest that the agroforestry livelihood is highly resilient to the dryland hazards, thus has potential to secure a high and sustained human well-being of the dryland agroforestry practitioners.

Chapter 5: Distribution and ecology of trees in Eastern Africa drylands

Roelandt Kindt, Thomas Groen, Jan de Leeuw and Jens-Peter Lilleso

In this chapter, we first provide a description of the natural vegetation of the drylands of Eastern Africa. The reason for doing this is that there is little information on the distribution of individual tree species, a lacune which can be overcome however when using information on the distribution of vegetation types as an approximation of the distribution for individual tree species. Second, we provide an analysis of the principle natural factors that influence regional variation the structure or physiognomy of the vegetation, with particular attention for variation in tree cover and height. In the final section, we provide some reflection on the impacts of tree utilization on the distribution of trees.

5.1 Potential natural vegetation

The distribution of natural vegetation types provides a good approximation of the distribution of individual tree species at continental to national scales. The *Vegetation Map of Africa* developed by Frank White [13] delineates natural vegetation types such as the Somalia-Masai, Sudanian and Zambezian areas of endemism. Empirical distribution data for individual tree species were not available during the compilation of the vegetation map of Africa and this paucity of empirical species distribution data still holds today. In a situation like this maps of natural vegetation types can be used to infer the distribution of individual tree species [14] and generate maps that for example, discriminate where a particular species will be able to establish and provide, or alternatively fail to survive and provide desirable products and benefits. This inferential logic has been used to develop a species selection tool now available as an interactive map that can be used to select 'the right tree for the right place' throughout Africa [15]. Following this, a new higher resolution interactive vegetation map and species selection tool (the VECEA map, www.vegetationmap4africa.org) was produced for seven countries including four in the Eastern African region considered in this report (Ethiopia, Kenya, Malawi, Tanzania and Uganda [16]. Most of the descriptions of natural vegetation types given below were summarized from the documentation of the VECEA map.

The vegetation map of Africa was based on earlier vegetation maps of the 1960s and 1970s and it is possible that changes in temperature or rainfall that occurred since then may have shifted boundaries between vegetation types [17]. It would be possible in theory to adjust vegetation boundaries to climatic conditions today by calibrating the older map to the climatic conditions during production of the vegetation maps, and then predicting the adjusted boundaries based on more recent climatic conditions. Likewise it is theoretically possible for floristic studies to document recent vegetation shifts, although tree longevity may complicate analysis. However, ecotones or zones of gradual transition do exist between many vegetation types. It remains an open question whether widths of ecotones are substantially larger than the spatial shift in vegetation types due to recent climatic changes.

Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket (synonym: deciduous bushland) is the climax vegetation type of a large part of the arid and semi-arid lands of Eastern Africa (Figure 5.1b) where rainfall is low and bimodal. It characteristically is a dense bushland of 3 to 5m tall with scattered emergent trees up to 9m. Emergent species have well-defined trunks which carry the crown well above the main canopy; they are virtually absent from the driest areas. Most of the characteristic species of the main canopy underneath these emergents are multiple-stemmed bushes or small bushy trees branched near the base. In higher rainfall areas (especially on rocky hills), the emergent trees occur closer together and are somewhat larger (but only exceptionally taller than 10m). Some authors have categorized this physiognomic variant as woodland. Locally thickets are formed that are impenetrable.

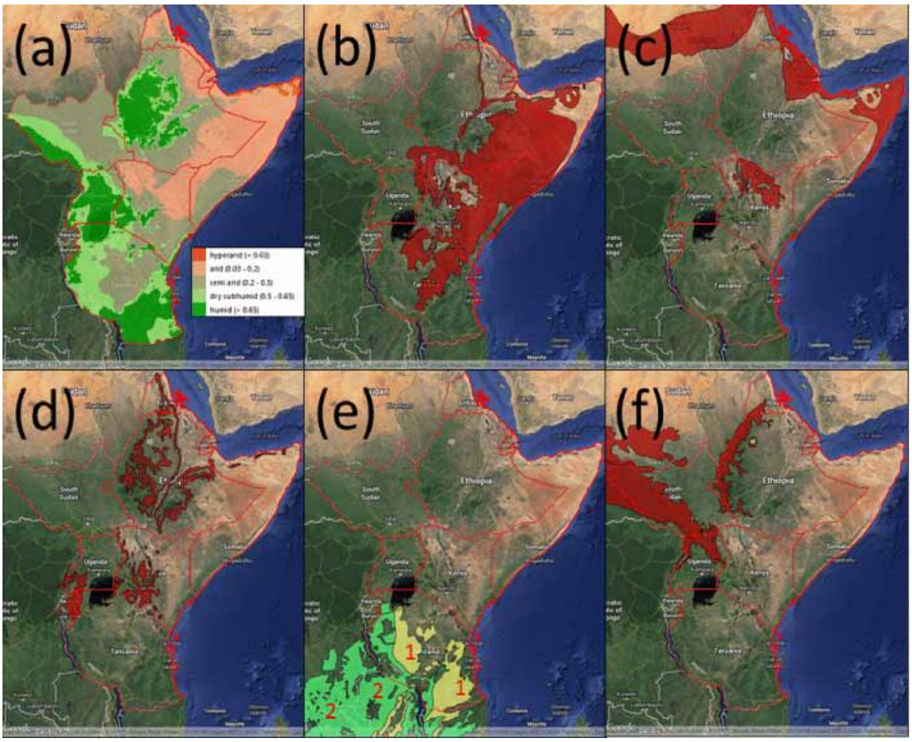


Figure 5.1 Aridity index (a) and major natural vegetation types in Eastern Africa: (b) Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket; (c) Somalia-Masai semi-desert grassland and shrubland; (d) mosaic of Somalia-Masai Eastern Africa evergreen and semi-evergreen bushland and thicket and secondary (biotic) *Acacia* wooded grassland; (e) Drier (1) and wetter (2) Zambezian miombo woodland; (f) Sudanian undifferentiated woodland and Sudanian woodland with abundant *Isoberlinia.* Aridity index derived from the CGIAR-CSI Global-Aridity and PET Database (http://www.cgiar-csi.org; [18] [19]. Distribution of vegetation types obtained from URL http://www.worldagroforestry.org/our_products/databases/useful-tree-species-africa, according to Kindt et al [15] [16] work by White [13]. Country boundaries obtained from the GADM database of Global Administrative Areas (URL http://www.gadm.org/). Map generated by R. Kindt in [20] with OpenLayers plugin to add the Google Hybrid layer.

There is appreciable variation in floristic composition within deciduous bushland and thicket, but species of Acacia, Commiphora, Grewia and various Capparidaceae species (e.g. Boscia, Cadaba and Maerua) are nearly always present. The dominant Acacia species and some of the Commiphora species are spinous. Most species are deciduous (losing their leaves simultaneously and usually for several weeks or months). Evergreen species occur, but never contribute more than 10% to the phytomass. Characteristic species of the main canopy include *Acacia bussei*, *A. mellifera*, *A. nilotica*, *A. reficiens*, *A. senegal*, *A. thomasii*, *Commiphora africana*, *C. campestris*, *C. edulis*, *C. erythraea*, *C. mollis* and *C. schimperi*. Emergent species include *Acacia tortilis*, *Adansonia digitata* (often only 8m tall with a short but massive trunk), *Delonix elata*, *Melia volkensii* and *Terminalia spinosa*.

Semi-deserts are areas where the differences in soil characteristics (such as soil colour) are more conspicuous than the vegetation itself, but where the plants are still sufficiently evenly distributed so that the vegetation can be further classified in physiognomic categories such as "semi-desert grassland" and "semi-desert shrubland". In the Greater Horn of Africa, semi-desert vegetation occurs in areas that are more arid than those where Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket typically occur (Figure 5.1c). Where annual rainfall is between 100 and 200mm in the Somalia-Masai region, semi-desert grassland (dominated by grasses such as *Centropodia glauca*, *Eragrostis mahrana* and *Panicum turgidum*) occurs on deep sand. Under similar rainfall conditions, semi-desert shrubland occurs on stony soils.

Evergreen and semi-evergreen bushland and thicket occurs on the drier slopes of mountains and upland areas in Eastern Africa, which rise from the lowlands from the Somalia-Masai region all the way to central Tanzania. It often forms an ecotone between Afromontane single-dominant *Juniperus procera* forest and deciduous bushland. This vegetation type occurs in the dry sub-humid zone (Figure 5.1d) with mean annual rainfall of 500 to 850mm irregularly distributed throughout the year but with two main peaks. Evergreen bushland varies greatly in species composition and richness, but certain woody species that are nearly always present in the Somalia-Masai region include *Acokanthera schimperi*, *Carissa spinarum*, *Dodonaea viscosa*, *Euclea divinorum*, *Euphorbia candelabrum*, *Olea europaea* ssp. *cuspidata* (synonym: *Olea africana*), *Tarchonanthus camphoratus* (especially in disturbed areas) and *Vepris simplicifolia.* The Lake Victoria floristic region has a floristically poorer evergreen bushland variant.

Where domestic or wild animals are numerous, various *Acacia* species have replaced Eastern African evergreen bushland. It is therefore typical to find *A. drepanolobium*, *A. hockii*, *A. kirkii* and *A. seyal* occurring together with evergreen species. Evergreen bushland communities of the Lake Victoria region have been replaced by wooded grassland dominated by *Acacia hockii*, *A. gerrardii*, *A. kirkii*, *A. senegal* and *Euphorbia candelabrum*. In the documentation of the VECEA map, it was suggested that 'biotic Acacia wooded grassland' is an alternative steady state of potential natural vegetation (corresponding to disturbance by animals) to the steady state of evergreen bushland (corresponding to limited disturbance by animals). The degree of grazing pressure therefore determines the proportions of biotic Acacia wooded grassland compared to evergreen bushland in the Greater Horn of Africa.

Miombo woodland is floristically and physiognomically very different from other types of African woodland. It is nearly always dominated by species of *Brachystegia* either alone or with *Isoberlinia angolensis*, *Julbernardia globiflora* or *J. paniculata*. Most miombo woodlands are semi-deciduous, but some are completely deciduous and some are almost evergreen. Miombo woodland is the prevalent vegetation throughout the greater part of the Zambezian region (a region with unimodal rainfall rather than the bi-modal rainfall experienced in the Somalia-Masai region), especially on the main plateau and its flanking escarpments. In the Greater Horn of Africa (especially in the countries that we focused on), Miombo woodland only occurs in Tanzania (Figure 5.1e), although a closely related type occurs in coastal areas of Kenya (this other type is 'Zanzibar-Inhambane transition woodland', a vegetation community that is intermediate between Zanzibar-Inhambane forest and Zambezian woodland and that is dominated by *Brachystegia spiciformis*). Miombo woodland generally occurs in dry sub-humid areas, and drier and wetter sub-types can be distinguished (Figure 5.1e). Whereas some authors (including White [13]) expected that, on moister and deeper soils in higher rainfall areas, Miombo had replaced Zambezian dry evergreen forest, the interpretation that all these areas previously supported forest is not generally accepted (P. Smith and J. Timberlake, pers. comm.).

In Eastern Africa*,* **Sudanian woodland** (as defined and mapped by White [13]) principally occurs in South Sudan, Ethiopia and Uganda. In a similar situation as with miombo woodland, Sudanian woodland generally occurs in areas that experience unimodal dry subhumid conditions (Figure 5.1f). Sudanian woodland was mapped as different vegetation types in the VECEA map: (i) dry *Combretum* wooded grassland; and (ii) *Vitellaria* wooded grassland. *Combretum* wooded grasslands are among the most widely distributed wooded grassland vegetation types of Eastern Africa. In wetter areas, various *Combretum* species are associated with larger-leaved species of *Terminalia* (especially *T. glaucescens* and *T. mollis*). In drier areas, *Combretum* species are associated with smaller-leaved *Terminalia* species: *T. brownii* in Kenya and Uganda and *T. sericea* in the "monsoon sector" of Tanzania (i.e. areas with a one-season summer rainy season typically). White [13] does not use the definition of *Combretum* wooded grassland, but the sub-type of "Ethiopian undifferentiated woodland" as described by White (1983 p. 107) is virtually equivalent to Combretum-Terminalia woodland and wooded grassland as described in the recent atlas of potential natural vegetation types of Ethiopia.

The shea butter tree *Vitellaria paradoxa* (synonym *Butyrospermum paradoxum*) is endemic to the Sudanian region [13]. *Vitellaria paradoxa* often replaces *Isoberlinia doka* in secondary grasslands where *Isoberliniadoka* dies out because of frequent cultivation.

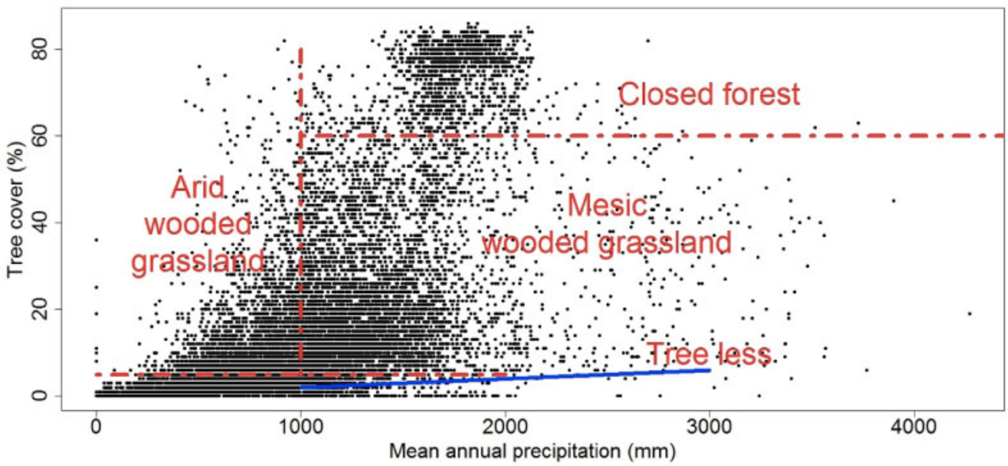


Figure 5.2 Relation for the African continent between tree cover (%) derived from MODIS[21] imagery and mean annual precipitation from WorldClim. Categories in red according to [22] and [23].

5.2 Ecology of trees and vegetation physiognomy

A number of factors affect the vegetation structure or physiognomy of dryland vegetation. This section focuses on tree cover and height, first because these are traits available from satellite-borne observations and secondly because many physiognomic studies consider these descriptors. Tree cover and height are also principal descriptors used in physiognomic classification schemes to differentiate between vegetation types such as forests, woodlands, wooded grasslands and bushland. Other parameters, such as stem diameter, density, age, biomass and species composition are equally important in the context of resilience for human use.

Abiotic factors including climate

Important abiotic factors that affect tree cover include soil properties and climatic factors such as rainfall (Figure 5.2) and temperature as these are 'direct environmental gradients' that influence resource gradients relevant to plant growth and plant development and therefore their potential distribution [24]. In general there is the notion that in arid systems resource limitations, especially water availability, are the major determinants of tree cover, while in more humid systems, disturbances such as fire determine the tree cover [25] [26] [22]. As a broad rule of thumb, systems with mean annual precipitation (MAP) below 1000mm are considered as drylands [23]. In drylands, nutrient limitation is hardly ever considered to be a limiting factor [27]. Empirical inference on tree distribution using either field based methods [25] or satellite derived information [23] have shown that MAP sets an upper limit to the tree cover that can be found up to approximately 1000mm of mean annual rainfall (Figure 5.2). This means that the maximum tree cover that can be expected is a function of MAP, but that the actual tree cover could be much less due to other factors (*i.e.*, factors leading to changes between potential vegetation [described under “Potential natural vegetation”] and actual vegetation).

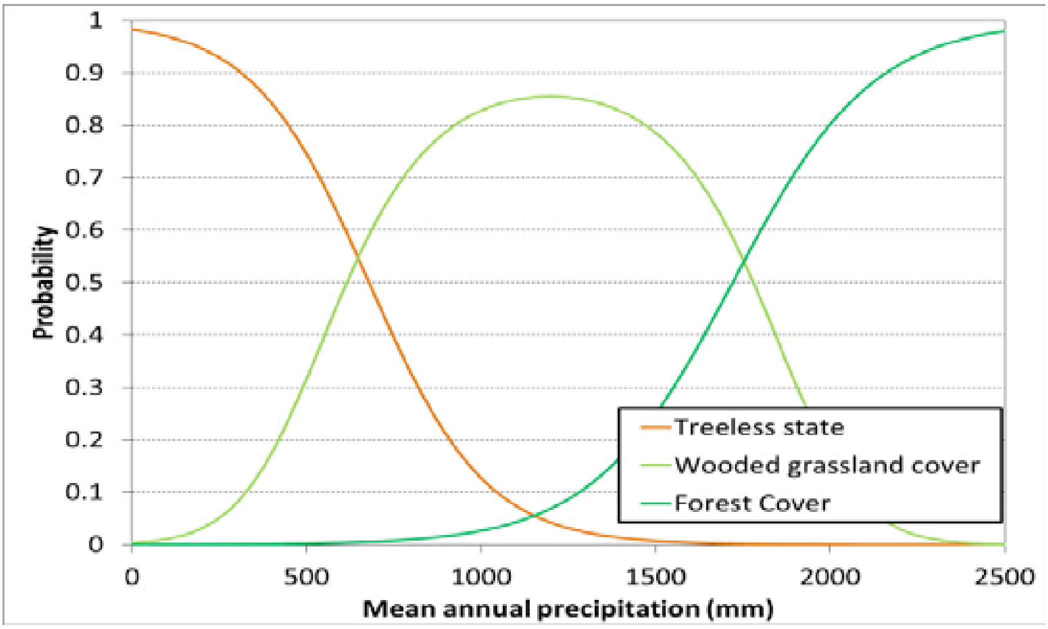


Figure 5.3 The probability of occurrence of three physiognomic vegetation classes in Africa as a function of rainfall on the African continent: a treeless state, a sparsely woody to intermediate density wooded state and a forested state. Probabilities from [22]

Given a certain amount of rainfall (MAP), several states of tree cover can exist: (i) a tree less state; (ii) a wooded grassland state; and (iii) a closed forest state [22]. In Figure 5.2 we can clearly see that under a given amount of rainfall (MAP), different types of tree cover can be found. For example at 500mm MAP, both a treeless and a wooded grassland state are almost equally likely (see also Figure 5.3). Which of the two states is actually found therefore depends on other factors.

As an alternative to MAP, Aridity indices combine both rainfall and evapotranspiration to provide a better representation of the available moisture for plant growth. Combining aridity with other relevant factors such as length of growing period provides a reliable set of parameters describing conditions that can distinguish between important biomes at the continental scale [28]. This can also be observed when plotting tree cover and height against aridity indices rather than MAP (Figure 5.4) displaying similar trends as described above. We also observe a generally lower tree cover for Eastern Africa. Around 99% of the Eastern African region has less than 60% tree cover and would be classified as Wooded Grassland in some vegetation classification schemes. This coincides with lower rainfall levels, a regional median MAP around 548mm against 740mm for the whole of Africa. Clearly high rainfall zones overlap with tall and closed forests (Figure 5.5).

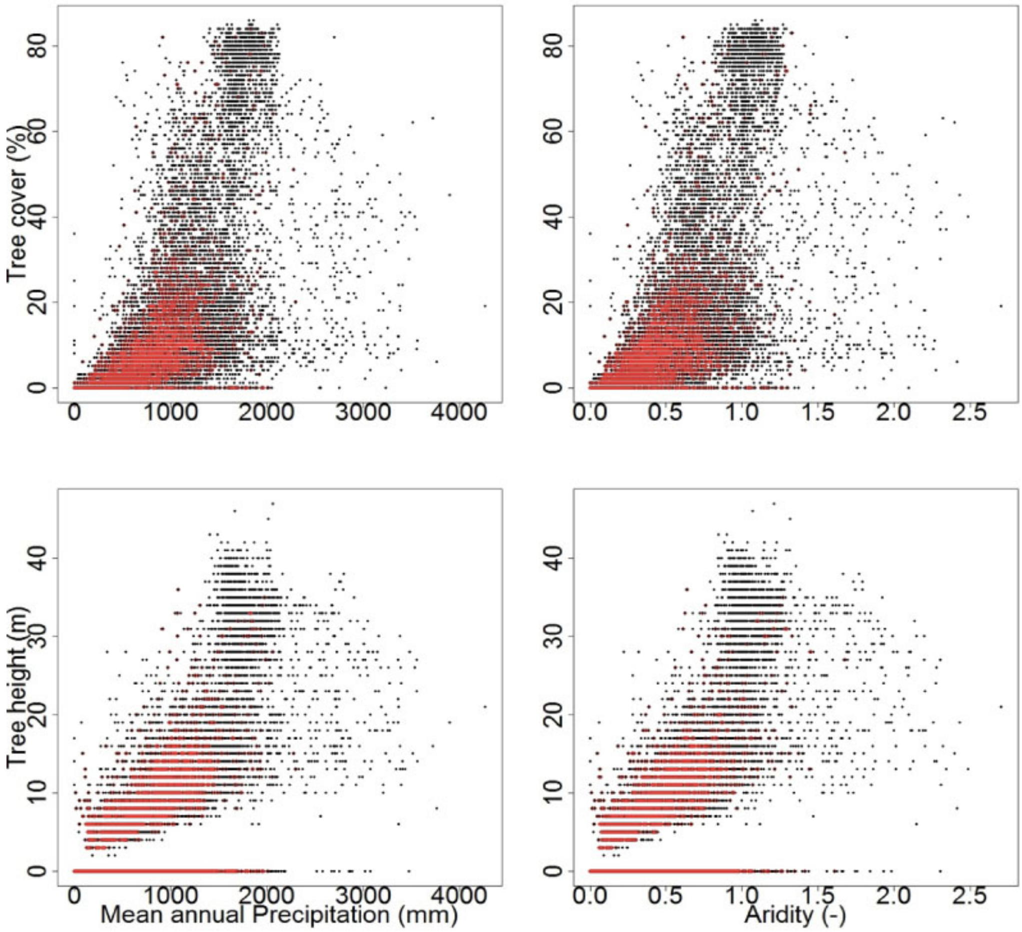


Figure 5.4 Tree Cover [29, 30] and height [31] as a function of mean annual precipitation (Worldclim) and aridity [19]. Red dots indicate plots in Eastern Africa.

Biotic factors and fire

Biotic factors include biotic interactions such as herbivory [32], competition with grasses [30] and fire [33] [34]. Fire itself is not a biotic process, but a mixture of biotic and abiotic factors influence its impact on trees. It is the biomass of grasses rather than trees that fuel most dryland fires. Only when grasses form a continuous layer of fuel with a fuel load of above 1500kg dry matter per ha is capable to carry the fire [35]. This is a situation occurring in the wetter drylands with annual rainfall above 1000 mm. The flammability of this biomass goes up at the start of the dry season when biomass is plenty and desiccating, which results in hot fires, which may damage trees [33]. Most savanna tree species are not really killed by fires, but we do speak of top-kill when trees are reduced to their belowground organs from which they have to resprout after a severe burn.

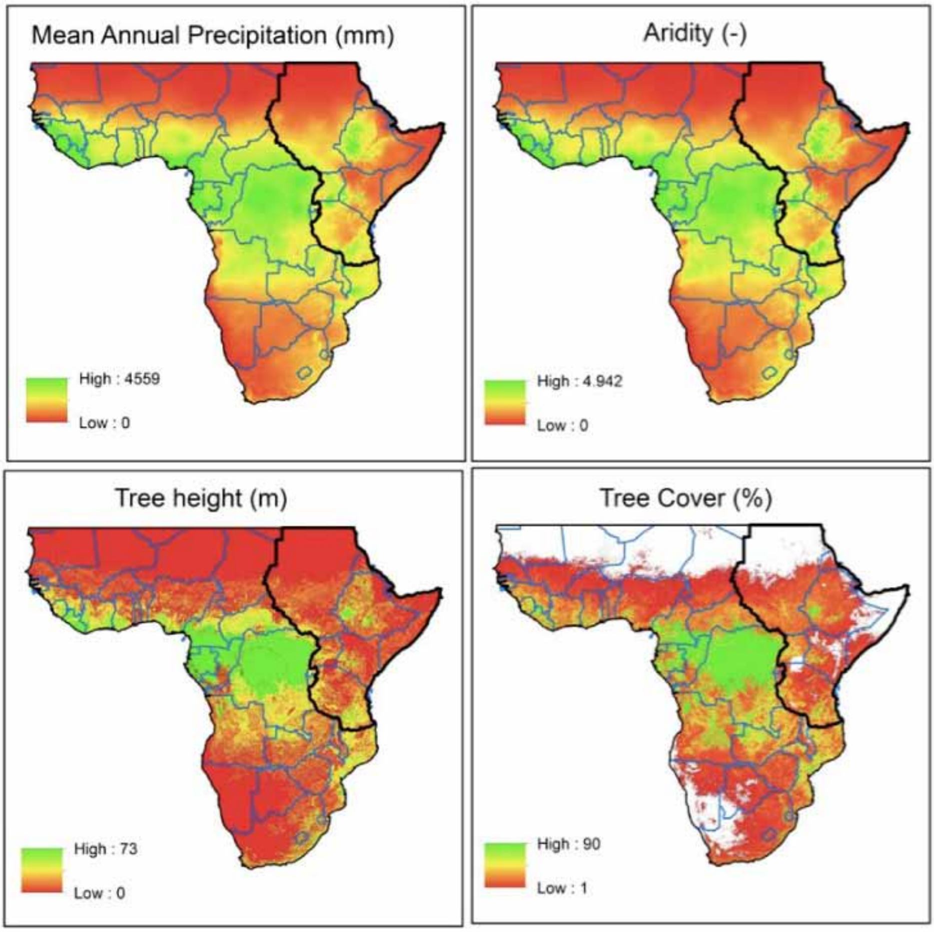


Figure 5.5 Maps showing the distribution of mean annual precipitation, aridity, tree cover and tree height for Sub-Saharan Africa. The black line indicates the subset of Eastern Africa that was included in the above figures.

Herbivore effects on tree cover and height are also complex and depend on the nature of the trees, the herbivores and the environmental setting. Firstly, herbivory can be broadly defined using two distinct approaches, browsing, related to the consumption of shrub and tree leaves, and grazing, referring to the consumption of the herbaceous layer [36]. Most dryland herbivores can be grouped into either of these two guilds, although some animals, such as goats or elephants, are so adaptable in their feeding strategy that they are referred to as intermediate feeders. Browsing clearly has a direct effect on trees in drylands as it reduces the leaf area of the plants, and through that, its photosynthetic activity and evapotranspiration. The extent to which browsers exert an effect on trees depends on the palatability, thorniness and height of the species. Taller trees are less susceptible to browsing than shorter trees [37], although not immune. For example, elephants are well known for their ability to tear down tall trees, giraffes (*Giraffa camelopardalis*) are clearly capable of accessing high positioned canopies, and even goats (*Capra spp.*) are well known for climbing into multi-stemmed trees to access higher located leaves. Grazing indirectly affects trees, as it reduces the fuel load, and thus the impact of fires on trees [33]. It also reduces competition for resources between trees and grasses [30]. However, this latter point is mainly an issue in the wetter systems that are more expected to be nutrient-limited rather than water-limited.

Clearly the above-mentioned factors that influence tree cover and height within the boundaries set by climatic and a-biotic effects are highly system specific, or apply to the wetter systems that have been discussed. An important aspect that relates to this is the human exploitation that to a large extent mediates these factors, such as control on burning, managing both the livestock and wildlife and the harvesting of plant organs. The lower than expected tree cover that can be observed in some parts of Eastern Africa such as the Ethiopian highlands or Uganda is partly attributable to the high population densities in these regions and subsequent exploitation.

5.3 The effect of tree management on tree cover

The above described factors thus set a maximum tree cover and height. Figure 5.2 shows that the maximum (threshold) achievable under certain rainfall conditions is not achieved in many situations. Exploitation and management of trees forms an important factor explaining why this maximum is not achieved. Within the potential and limitations to tree cover set by the factors described in section 5.2 actual tree will be dominantly determined by the way people exploit and manage trees. This section reviews the effect of tree management and exploitation on the actual density of trees in man-made landscapes.

Throughout the drylands of Eastern Africa there are several factors, which affect the intensity of management of trees. The first is a gradient going from systems where trees are not planted and exploited as they appear as a result of natural regeneration to systems where trees are planted for the benefits that they provide; mixed systems exist with naturally regenerated trees interspersed with planted trees. Tree ownership is an important factor determining the management beyond the seedling phase. While having planted a tree is an important factor, it does not always suffice to guarantee that the one managing a tree will be the (sole) beneficiary of this effort. Formal or informal land tenure arrangements are crucial to support tree tenure and the authority to determine, who profits from the benefits that managed trees provide. Land tenure is thus an important factor determining the intensity of tree management, and some relation exists between intensive tree management including planting, forcing of seedlings and managing of adult trees on lands with secure tenure, and less intensive or absence of management on open access lands. The relation is imperfect because private lands exist where trees are not managed while there are also many public lands where the use of land and trees is regulated by customary law and other institutional arrangements. However, tenure remains a crucial condition to create the environment, which makes investment in tree farming a viable option.

People exploit trees in drylands to derive various benefits from the various goods and services they provide. Some of these uses do not affect the production or survival of trees whereas other may have the effect of depressing the production and/or destroying the tree altogether. There is thus a gradient forcing uses with neutral effect to less or more intrusive tree uses, and below we provide a narrative describing the level of intrusiveness of tree uses, which are further described as the various ecosystem services in chapter six.

The harvesting of food from trees may range from harmless to intrusive depending on the intensity. The collection of fruits and nuts affects the reproductive strategy of trees and although many trees have an ability to also disperse through stoloniferous growth, seeds remain important to reproduce and to maintain genetic diversity. Broadly, two strategies can be defined in tree seed production. Some species produce many very small seeds, aiming at a high chance that some seeds will land in suitable locations to settle, but at the cost of providing these seeds with very little reserves. The second strategy is to produce very few bigger seeds that come with large reserves to make sure the seedlings get a good start at the beginning, but with the risk that these few expensive seeds all end up in unsuitable locations. Collection of fruits and nuts is likely to interfere more with tree reproduction in the second case. However, in harsh environments, such as arid and semi-arid savannas, the small seeds in high number - low survival strategy is adopted by many trees [38]. Overutilization and depletion of the seed bank may affect reproduction of trees in case of species with large seeds such as for example the shea butter tree. Where fruit trees are actively planted, this kind of extraction should have limited effects on the dynamics and persistence tree species.

The collection leaves from trees for human consumption (tree vegetables) or as a fodder for livestock reduces the trees' capacity for primary production. Depending on the season this can be more or less detrimental. When trees are (near) dormant (e.g. at the start of the dry period) removal of leaves will have little effect on the survival of a tree, as the leaves will have reached the end of their expected life time. However, defoliation during the growing period deprives the tree of its foliar tissue which it will try to compensate while mobilizing energetic resources. Repeated defoliation may deprive trees of these resources and lead to starvation and mortality. The provision of tree vegetables and livestock fodder should thus be managed carefully, and requires adequate tree tenure to allow this.

Harvesting of resins and gums may result in further decline of vegetation (tree) cover compared to what is expected naturally. We use the term "exploitation" to indicate that in this section the utilization of tree products is described from the perspective of tree ecology and its consequences for the difference between potential and actual distribution. The term "use of tree products" relates more to the perspective of providing services to human needs, which will follow in subsequent sections.

The collection of gums and resins may range from harmless to quite intrusive depending on the type of resins or gums (see section 6.2.7) harvested and the approach taken. Many resins and gums are harvested on an ad hoc basis from trees that are naturally oozing these substances, which would have low impact on the trees. Nevertheless, where commercial exploitation of gums and resins start to occur, caution has to be paid not to over-harvest these substances. Gums and resins play a vital role in the ecology of the trees in storage of essential elements, protection against insect attacks and transport within the stem. Examples are known of cases where resin extraction from *Boswellia papyrifera* for the production of Frankincense had clear negative effects on the survival and growth of trees [39].

Harvesting branches (e.g. for fuel wood) has a more distinct effect because a complete section of a tree is removed, including the leaves on the branches. This includes affecting the structural properties of the canopy. Also, breaking of branches creates a clear scar that makes a tree more vulnerable to insect and disease attacks. Complete harvesting the above-ground section of trees clearly resets the development of the above ground tree component completely. Harvesting complete stems may not necessarily kill the tree as many arid species can resprout after harvesting (essentially, being top killed by fire has the same result). Nevertheless, it has a profound effect on the state of a tree and in many cases it does require the re-establishment of a new tree that can take up to several years.

Roots are important organs for plants, allowing for access to sub-surface resources and providing stability. Although root harvesting normally happens after a tree has been chopped, it eliminates the possibility of re-sprouting, and also affects the structure of the soil, making it more vulnerable to erosion.

How the above mentioned exploitative uses of trees affect the tree population in an area depends on existing management systems by smallholder farmers and pastoralists, including aspects of usufruct, gender and tenure rights. Clearly, trees offer opportunities for use by people, but this can be done only sustainably when the multiple uses are coordinated. This poses a challenge in many drylands, because frequently trees do not belong to individuals but are a common good. Evaluation of management opportunities should therefore go beyond supporting current regeneration patterns and focus on active management, coordination of use and restoration.

Potential natural vegetation, and the abiotic conditions that set upper boundaries to tree cover, could be used as reference for restoration – both for understanding alternative restoration pathways and to actively promote useful, and therefore often over-exploited, dryland tree species. Above all however, secure tree tenure is required to stimulate an effective management of trees in the drylands of Eastern Africa.

Chapter 6: Benefits from the ecosystem services provided by trees

6.1 An ecosystem service perspective on benefits provided by trees

Jan de Leeuw, Mary Njenga and Ramni Jamnadass

Introduction

This chapter gives a synopsis of the benefits and resilience that people derive from trees and forests in Eastern African drylands. The synopsis is structured according to the four categories of ecosystem services used by the Millennium Ecosystem Assessment [40]; provisioning, regulating, cultural and supporting services. Provisioning services such as the supply of charcoal, for example, and cultural services are generally well recognized and appreciated because they provide direct benefits to people, and some are traded in markets and regulated by policies. Regulating and supporting services provide indirect benefits, which in spite of their critical significance to human well-being tend to be under-appreciated, go unnoticed and are typically ignored and not considered in decision-making [41]. Among the regulating services it describes the regulation of the micro- and macro-climate, the water cycle and soil conservation and erosion prevention. The cultural services treated in this synopsis include aesthetic, landscape, inspiration, tourism and other benefits. The supporting services include the cycling of nutrients and soil moisture and biodiversity, which support the primary production of trees that underpins the delivery of provisioning, cultural and regulating services. The chapter further reviews seven categories of provisioning services which trees provide including food, fodder, medicine and pesticide materials, oil, construction materials, wood fuel and gums and resins.

Each section gives a general description of the service, its demand, markets and value chains, supply including production system, management and harvesting practices and social aspects including benefits to households. The sections also address gender and equity, sustainability, partnerships, supporting policies and institutions and regional variations across countries and tenure of land and trees and how these issues influence benefits and management of trees. Some of these issues are more explicit in the provisioning services than other services. The chapter begins with a summary, which reviews how the benefits derived from trees influence the five types of livelihood capitals that are important for the provisioning of resilience.

Synthesis of resilience, ecosystem services and livelihood benefits provided by trees

The subsequent sections of this chapter (6.2 to 6.5) describe the benefits including resilience that trees provide through a variety of ecosystem goods and services. There are two contrasting ways through which tree-related ecosystem services and goods provide resilience. The first type of resilience is direct in nature and arises when trees continue to provide goods and services and/or resume production in case of drought or other hazards. We distinguish the following forms of type-1 resilience. The first is the case of organisms continuing provisioning of ecosystem goods and services during drought. Trees are less volatile in this respect than other organisms such as livestock and crops, because of their deep rooting system which allows access to water resources not available to these other life-forms. A second type-1 resilience is offered by organisms, which quickly resume providing goods and services when drought is over. Trees, which contrary to livestock experience little mortality during drought, are good examples of the second type of type-1 resilience because they normally recommence full production once drought is over. A third, not necessarily drought related type-1 resilience enhancing impact pathway arises when trees provide goods and services during the "hungry season", the period at the end of the dry season and the start of the rainy season, when foods from crops and livestock are inadequate to satisfy demand.

Type-2 resilience by contrast is indirect and arises when trees strengthen the livelihoods' buffering capacity in normal years, a buffering capacity that can be drawn upon when hazards arise. A first type-2 resilience is when organisms accumulate stocks of natural capital that can be drawn upon during drought. Trees offer this type of resilience because accumulated wood and other tree products offer people the possibility to at least mine such stocks thus ensuring a continued source of benefits and income even during the height of a drought. A second type-2 resilience arises when trees increase the primary production of agroforestry landscapes, thus increasing the benefits from crops, trees, livestock and other organisms. The supporting services described in section 6.3 are instrumental in this respect. A third type-2 resilience arises when financial institutions such as those established for payment for ecosystem services, ensure continued payment in case of hazards. The carbon credits developed in the Kasigau case study (section 7.7) are an example of this. There are other forms of indirect (type 2) resilience; apart from their obvious role in establishing natural capital trees also contribute to the development of human, social, financial and physical capital. Tables 6.1.1 to 6.1.4 summarize how each of these ecosystem goods and services, which are described in the rest of this chapter enhance type-2 resilience through their effect on the various livelihood capitals.

Supporting services

In this report we consider three ecosystem services supporting primary production and the diversity of tree life that underpins all provisioning, cultural and regulating services provided by trees. Table 6.6.1 describes how these three supporting services relate to the five livelihood assets. The effect of trees on soil fertility and soil moisture affects the human dimension of the livelihood because it enhances health and nutrition through greater production of foods and other provisioning services. It also indirectly leads to increased income from sales of provisioning, regulating (carbon credits) and cultural services (e.g. tourism). Tree species diversity supports the human livelihoods dimension through healthier people and nutrition through a greater variety of food and medicine. It also supports diversification in occupation and value chains as well as improvement of performance of trees through breeding, for example, enhancing resistance to pest and diseases attack. These supporting services, which generally are not well appreciated and accounted for, are a core element of resilience as they support the delivery of increased benefits of more productive and diverse palette of ecosystem services, which would not be delivered in the absence of trees.

Table 6.1.1 Livelihood resilience provided by trees though supporting ecosystem services supporting the five livelihoods assets.

Ecosystem services		Livelihood assets				
		Human	Social	Natural	Physical	Financial
Supporting services	Soil fertility	Greater health through increased crop and livestock production		Trees enhance soil fertility		Indirect impact on income from other services
	Soil moisture	Greater health through increased crop and livestock production		Trees enhance fraction of rain used for primary production		Indirect impact on income from other services
	Biodiversity	H&N enhanced through more diverse nutrition, medicine etc.	More diverse occupation through tree species diversity	Greater species diversity supplies greater diversity of tree benefits, opportunity for breeding		Greater diversity of tree product and service related value chains

H&N = health and nutrition

Regulating services

Table 6.1.2 outlines the role of trees in regulating ecosystems processes through proving shade, reducing wind and raindrops velocity and momentum, reducing runoff amount and speed, control floods hence improving soil temperatures, soil moisture and ground water recharge. Trees in drylands reduce the movement of dust reducing health risks of people and livestock from illnesses such as those of respiratory system. The nitrogen fixing tree species sequester carbon. Through these processes the micro and macro-climate of the ecosystem is regulated. Trees also protect land from erosion hence making it available for other uses such as settlement and agriculture. Nitrogen (N) fixing trees converts atmospheric N into organic form in plant tissues through symbiotic association of roots and special types of bacteria hence improving soil N. In turn trees through modifying the micro- and macro-climate of agroforestry ecosystems build the natural capital thus positively influencing overall productivity of dryland ecosystems.

Table 6.1.2 Regulating services

Ecosystem services		Livelihood assets				
		Human	Social	Natural	Physical	Financial
Regulating services	Micro-climate	Improve productivity of drylands hence implication on H&N		Provide shade, reduce wind and raindrops velocity and momentum, reduce body energy loss from livestock		Indirect impact on income from other services
	Air quality	Health by reducing dust		Reduce dust movement and offer soil cover		Same as above
	Macro-climate	Improve productivity of drylands hence implication on H&N		Carbon sequestration		Same as above
	Flood + groundwater control	Improve productivity of drylands hence implication on H&N		Reduce runoff amount and speed hence improved soil moisture and groundwater recharge		Same as above
	Erosion control	Improve productivity of drylands hence implication on H&N		Reduce runoff amount and speed hence improved soil moisture, regulate water quality, protect land making it available for settlement and agriculture		Same as above
	Pest and disease control	Health of human and livestock				Same as above

H&N = health and nutrition

Cultural services

Trees provide non-material benefits, such as spiritual, recreational, aesthetic, inspirational and education that is passed through generations. People appreciate and adore trees, which have a positive impact on them psychologically, and which can be used in traditional ceremonies for example, for brewing beer. Trees mark boundaries of land hence improving social cohesion and mutual respect. Information presented in table 6.1.3 further shows that, local communities in drylands earn income through, for example, running community-based conservancies or by offering guided tours.

Table 6.1.3 Cultural services

Ecosystem services	Livelihood assets				
	Human	Social	Natural	Physical	Financial
Cultural services	Traditional knowledge passed through generations	Trees mark boundaries of land hence improved social cohesion and mutual respect. Trees are used in making beer, during traditional ceremonies and also for inspiration and spiritual.	Recreational and aesthetics beauty	Shade for meetings and education	Income from tourism

Provisioning services

Finally trees are the natural capital underpinning the provisioning of tree-related foods, fodder, medicine, oils, construction materials, wood fuels, gums and resins and other products not discussed in this chapter. The provisioning of these goods would not be there without trees, and as other capital it requires investment and careful management to ensure there is sufficient natural capital in the forms of trees to supply the various benefits to people.

Table 6.1.4 shows that all seven categories of goods that trees provision enhance the human capital through improved health and nutrition. The collection, processing and marketing of tree-related products also strengthens social assets. Construction wood is an important ecosystem service underpinning the physical assets of dryland livelihoods. All seven provisioning ecosystem goods also support financial capital dimension of dryland livelihoods through product sales.

A detailed account of supporting, regulating, cultural and provisioning services provided by trees are discussed in section 6.2. The sections also demonstrate the importance of having secure tenure of land and trees as they affect the benefits that people derive from trees as well as the management. Where people have more secure tenure they have access to the benefits and also manage the trees better with a hope to continue reaping the benefits for themselves and for future generations. The more communities are socially organized and connected to different institutions such as government, private sector research and development organizations in respect to harvesting, processing and marketing determines how well and effectively they benefit and manage trees. Enabling policies and regulations, especially those that have been internalized by local communities, promotes harmonious relationships among them. Peaceful relationships are also experienced between the local people and other individuals and institutions, thus creating a conducive environment for sustainable NRM in drylands.

Table 6.1.4 Livelihood resilience provided by trees through provisioning of ecosystem goods supporting the five livelihoods assets.

Ecosystem goods		Livelihood assets				
		Human	Social	Natural	Physical	Financial
Provisioning services	Food and nutrition	H&N through fruits, leaves and staples consumed	Product Sharing, SN while collecting	NC provisioning food		Income from sale
	Fodder for livestock	H&N through consumption of animal products	Status from livestock and ceremonial use	NC provisioning fodder and forage		Income through sale of animals and animal products
	Medicine	Health	Associations among herbalists	NC provisioning medicine		Income from sale
	Oil	H&N from cooking and cosmetics	SN in processing, harvest and marketing	NC provisioning oils		Income from sale of raw material and oil products
	Construction materials	Health protecting from weather and greater security		NC provisioning construction materials	Fences, houses, furniture	Income from sale of wood and timber
	Wood fuels	H&N from cooked food	SN during fetching, production and marketing	NC provisioning wood fuels		Income from sale of firewood and charcoal
	Gums, resins	Health from sanitation detergents	SN from harvest, processing and marketing and ceremonial use	NC provisioning gums and resins		Income from sale and payment for collection

H&N = Health and Nutrition; SN = social networks; NC = natural capital.

6.2 Provisioning services

6.2.1 Food and nutrition – Fruits, nuts, vegetables and staples from trees

Katja Kehlenbeck and Ramni Jamnadass

Numerous tree species in Eastern Africa drylands provide edible fruits, nuts, edible oils, vegetables (leaves) and pulse-like seeds. Dozens of indigenous fruit tree species (IFTs), although relatively unknown in global markets, are crucial for food security, nutrition and incomes. Many of the wild fruit species have good potential for domestication and on-farm production [42]. Women are often strongly involved in and benefit from wild fruit collection, processing and trade [43]. Due to economic and human population growth and increasing urbanization, fruit markets in sub-Saharan Africa (SSA) are predicted to grow substantially, e.g. by 5.7% per year in Kenya (calculation of ICRAF based on [44]). Cultivation of domesticated and wild fruit species on farms diversifies the crop production options of small-scale farmers and can bring significant health, ecological and economic revenues [45]. However, research and development has focused mainly on exotic fruits, while indigenous ones are largely neglected.

Table 6.2.1.1 Nutrient contents of selected African indigenous and exotic fruits, leaves (used as vegetables) and seeds per 100 g edible portion (high values are highlighted in bold).

Species	Energy	Protein	Vit C	Vit A (RE)	Iron	Calcium
	(Kcal)	(g)	(mg)	(µg)	(mg)	(mg)
Indigenous fruits:						
Adansonia digitataL.: pulp	340	3.1	150-**500**	0.03-0.06	1.7	360
Grewia tenax (Forrsk.) Fiori	N.A.	3.6	N.A.	N.A.	7.4-20.8	610
Sclerocarya birrea Hochst.	225	0.5	68-**200**	0.035	0.1	6
Tamarindu sindica L.: pulp	270	4.8	3-9	0.01-0.06	0.7	260
Ziziphus mauritiana Lam.	21	1.2	70-165	0.070	1.0	40
Exotic fruits:						
Guava (Psidium guajava L.)	68	2.6	228	0.031	0.3	18
Mango (Mangifera indica L.)	65	0.5	28	0.038	0.1	10
Orange (*Citrus sinensis* L. Osbeck)	47	0.9	53	0.008	0.1	40
Pawpaw (Carica papaya L.)	39	0.6	62	0.135	0.1	24
Vegetables:						
Adansonia digitata L.: leaves boiled*	74	3.7	20	1.86	3.1	313
Tamarindus indica L.: leaves boiled*	104	4.2	2	0.20	4.1	403
Moringa oleifera Lam.: leaves boiled*	81	8.8	69	6.99	4.8	434
Seeds:						
Parkia biglobosa (Jacq.) R.Br. ex G.Don: seeds dried*	445	32.3	6	0	33.2	291
Vitellaria paradoxa C.F.Gaertn.: seeds dried*	586	6.8	0	0	3.4	100

RE = retinol equivalents. * = data from West Africa. Source: [46] (compiled from different sources) and [47]

In Kenya alone, about 400 indigenous fruit tree species are documented [48] and said to contribute much to food and nutritional security and livelihoods of rural communities, particularly during periods of food shortage. A number of fruits and leaves of indigenous trees occurring in the drylands have a high vitamin and mineral content [46]

Leaves can be high in protein and vitamin A (e.g. *Moringa oleifera* leaves), while seeds can provide fat (e.g. *Vitellaria paradoxa* seeds) and protein (e.g. *Parkia biglobosa* seeds). Fruits are often intensely rich in vitamins and sometimes even minerals, e.g. 40-100g of the berries of white cross berry (*Grewia tenax*) supply the daily iron requirements of an under eight-year old child, while 10-20g of baobab (*Adansonia digitata*) pulp (or a glass of its juice) covers this child's daily vitamin C requirement. In addition to micronutrients, the high sugar content of some fruits, such as the fruit pulp of tamarind (*Tamarindus indica*) and baobab, make them important sources of energy (see Table 6.2.1.1).

Current fruit consumption in Eastern Africa – with a daily average of only 36g per person [49] – is far below the recommended daily amount of 400g fruits and vegetables per person [50]. A case study of 104 households in the drylands of Mwingi District, Eastern Kenya, showed that as little as 28g of fruit was consumed per person per day, 19g from indigenous fruits and 9g from exotic ones [46] - see case studies below. A range of factors constrain fruit production and consumption in drylands (details below). Climate change will most probably contribute further to that challenging situation by shifting the natural geographic ranges and reducing density and productivity of some wild fruit tree species [51].

Local consumption, commercial demand, and markets and value chains

Consumption data for dryland tree food products are difficult to collect due to the huge diversity of the wild tree species used for food, the highly seasonal consumption, which is challenging to capture, and the very location-specific use of some edible tree products. The following case studies illustrate use and consumption of fruits in Uganda and Kenya.

- In a study performed [52] in two districts of Uganda, 150 respondents (50% female) were asked about their collection and consumption of desert date (*Balanites aegyptiaca*) fruit pulp, leaves and seed oil. In Adjumani district, less than 5% of respondents reported using the leaves, while in Katakwi district all respondents consumed leaves and harvested on average 150kg per household (95kg consumed, 55kg sold) in the five months of the harvest season (November-March). In Adjumani district, 44% of respondents reported using the fruit pulp and 53% the oil from the seeds, but in Katakwi only 9% and 0%, respectively. Children were mentioned as the main fruit collectors within the household by almost 50% of the respondents.
- In Mwingi district, Eastern Kenya, a survey of 104 households revealed a mean daily fruit consumption of only 28g per respondent, 19g from indigenous and 9g from exotic fruits [46]. While no significant difference in wild fruit consumption was found between male and female respondents, a clear difference existed among the age classes. Children and young adults below 20 years reported consuming about 23g of wild fruits per day, adults (aged 20-49) about 16g and the elderly (aged 50 or older) only 9g (P. Simitu, pers. comm.). There was also a high seasonality of wild fruit consumption throughout the year with peaks in February-April and June-August, and lean seasons in May and January (Fig. 6.2.1).

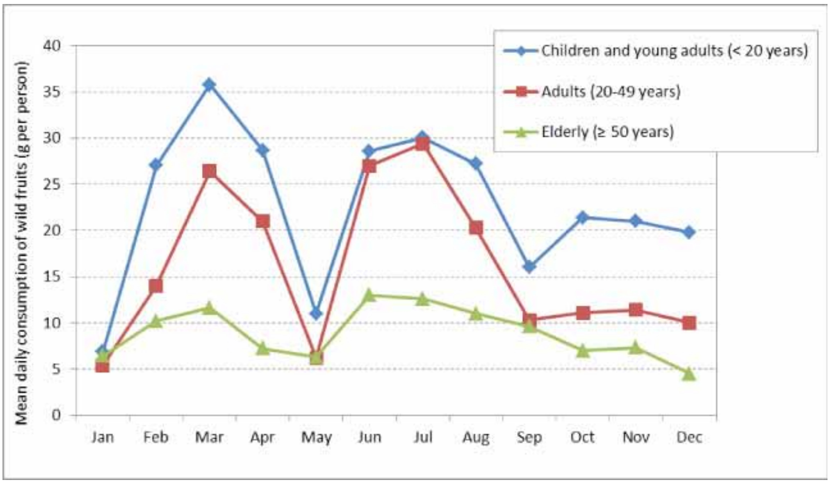


Figure 6.2.1.1 Mean daily consumption of wild fruits in grams per person during the course of the year, separately for three different age groups of respondents (Source: P. Simitu, unpublished data).

Data on consumption of many wild fruit trees is not the only challenge; data on the nutritional value of wild fruit is also difficult to find. Due to the high diversity of these species, chemical analyses have focused on a few 'flagship' species such as baobab and tamarind. A recent literature review of the nutrient composition of ten selected African fruits, eight of them occurring in Eastern Africa drylands, revealed a low number of reliable publications and high variability with respect to certain nutrient contents [47]. For example, the mean vitamin C content of baobab pulp ranged from 126mg to 509mg per 100g of edible portion, according to the reviewed papers. There is need to collect and publish information in databases such as FAO's INFOODS database (http://www.fao.org/infoods/infoods/tables-and-databases/en/) or in food composition tables such as the one available for West African food items, which includes some indigenous fruit tree products [47].

Market and value chain studies on dryland fruits are rare, focusing mostly on West and Southern African drylands in the case of wild fruits [42] and on commercial exotic fruits. However, below are two case studies from Eastern Africa.

- A pilot study on processing of the indigenous *Balanites aegyptiaca* (desert date) in Uganda [52] documented the use of different processing techniques used in two districts. In Katakwi district, desert date leaves were collected mainly by women and girls who cut branches and twigs from the tree and then plucked off the leaves. The boiled leaves were either sold at the market or used for home consumption after being pounded and cooked again [52]. However, no drying of leaves was reported; this limits the consumption of this vegetable to the harvest season between November and March. In Adjumani district, whole or depulped desert date fruits were dried to extend their shelf life. Nuts were dried and cracked; the seeds thus obtained were roasted, ground and boiled in water to extract the oil. From 2.5kg of seeds, 1 litre of oil could be extracted, which could be stored for 4-6 months.

- In three dryland districts of Eastern Kenya (Kitui, Mbeere and Mwingi), [53] studied the marketing of *Vitex payos* (black plum) fruits. All 114 randomly selected respondents (including 63 women) were involved in collection and consumption and 95 in selling of the fruits (mainly women). Fruits were consumed by all household members (male, female, adults and children). The fruit prices at the farm gate or in local markets were relatively low with USD 0.31-1.50 for one 20-litre bucket, while in urban centres, such as Kitui town, the same bucket was sold for USD 1.00-2.50. Transport may cost up to USD 0.25 per bucket, depending on the distance [53]. The respondents mentioned high post-harvest losses during storage and transport of the fresh fruits. Overall profit for the fruit collectors was rated as low, but respondents still highlighted the importance of this activity for their overall household income.
- For mango in Kenya, [54]reported farm gate prices of about USD 0.01-0.02 per fruit for a small-fruited local variety, and USD 0.06-0.08 per fruit for a large-fruited local or an improved variety in 2010. Most of the fruits are bought by middlemen, who then transport the fruits to urban markets, fruit processors and exporters. At urban markets such as in Nairobi, prices for small-fruited local varieties were USD 0.05-0.1 per fruit and USD 0.2-0.3 for large-fruited local or improved varieties in 2011, depending on season and location.

Description of the production system, including sustainability

For commercially-grown tree crops, such as mango or citrus, production data are often available from national institutions such as the Ministry of Agriculture (MoA). In Kenya, for example, the MoA together with the Horticultural Crops Development Authority (HCDA) publish a report each year on current area, production and value of selected horticultural crops, including fruits [55]. Further work is underway by the Kenya Agricultural Research Institute (KARI) on some lesser known exotic species, including guava, tree tomato and pomegranate and the indigenous fruit, tamarind. The KARI stations in Katumani and Thika are particularly involved (see Table 6.2.1.2 for details).

Table 6.2.1.2 Work on underutilized exotic and indigenous fruits currently performed by KARI in Katumani, Eastern Kenya, under the 'Horticulture and Industrial Crops' program, compiled by Fatuma Omari Ghelle

Project Title	Promotion and Commercialization of Selected Underutilized Fruit Trees in Semi-Arid Kenya for Food and Nutritional Security
Duration	July 2010 to June 2015
Donor	KARI/KAPAP (World Bank-supported)
Fruit species included	Guava (*Psidium guajava*), tree tomato (*Cyphomandra betacea*), loquat (*Eriobotrya japonica*), jack fruit (*Artocarpus heterophyllus*), pomegranate (*Punica granatum*), *Annona* species (custard apple, cherimoya and soar sop), white sapote (*Casimiroa edulis*), tamarind (*Tamarindus indica*), date palm (*Phoenix dactylifera*).
Activities	• Baseline surveys on occurrence, production and use of the mentioned fruits • Germplasm collection from the different target areas, maintenance on station in mother blocks, propagation in attached existing nurseries and in newly implemented community-based nurseries, and evaluation of the materials on-station and on-farm • Development, testing and modifications of tree management technologies, including tree fertilisation, control of pests and diseases (focusing on integrated pest management), pruning or dealing with soil salinity problems • Developing new and modifying existing simple and cost effective processing methods for the mentioned species (on-going already for guava). • Analyses of nutrient composition of lesser known species (if funds are available).
Expected impact	• Underutilized fruits contribute to family food and nutrition security and income generation, as well as to production of feed, firewood and timber. • Increased availability of quality planting material which will encourage farmers to grow more of these fruits hence contributing to the 10% tree cover requested by the Agricultural Act CAP 318 from 2009. • New marketing channels and processing technologies developed.

For most of the indigenous food trees, no official production data is available due to the difficulties in obtaining yield data from natural habitats (only a few controlled trials exist for exact yield assessments) and the often-huge variability of the yield per tree caused by environment and genetic factors. In some cases, harvest of fruits or leaves is performed in an unsustainable manner, thus, threatening the populations of the wild trees, as shown by the two case studies below.

In Uganda, desert date was mainly harvested not from farms but from the wild (84%), close to homesteads [52]. Only 7% of the respondents reported to have planted a desert date tree, mainly around their homestead, but 57% highlighted a negative influence of the tree on crop yields. Very little management was applied to the trees, including weeding and pruning for on-farm trees (to reduce shading). While fruit and nut harvesting was mainly done by just collecting the fruits that had fallen on the ground under the tree, leaf collection was performed by cutting whole branches and twigs. Respondents were aware of the unsustainability of their leaf harvest techniques, but still preferred them noting that they were more comfortable while picking the leaves, to save time and to reduce accidents.

In three surveyed districts of Eastern Kenya, 69% of the respondents had *Vitex payos* trees on their farm (mostly from natural regeneration or remnants from the former vegetation), while 31% collected fruits only from wild trees [53]. On-farm trees were managed by pruning by 83% of the respondents to reduce shading of crops. Fruit harvest was mainly done by collecting fruits that had fallen on the ground under the trees or by climbing and shaking trees or single branches. Although the harvest technique can be regarded as sustainable, abundance of trees in Kitui district was said to be decreasing due to high grazing pressure on young seedlings [53]. Almost 40% of the respondents also mentioned that they cut *Vitex payos* trees for fuelwood and timber, which may further contribute to decreasing abundance.

Social aspects: Importance of local consumption and of markets to households; gender and equity

The following examples illustrate income generation from edible tree products in drylands. Mango production is an important income generating activity in dryland areas, where enough rainfall is received or irrigation is available. A projection of the profitability of mango growing in Kenya by Krain [56] revealed that intercropping was more profitable than monocropping (Table 3.2.1.3). One acre planted with 50 mango trees as well as maize and beans will give an annual net income of almost 17,300 KES and an internal rate of return of 47%.

Table 6.2.1.3 Economic indicators of mango production per acre (50 trees per acre over a 25 year investment period)

Economic Indicator	Mango – Monocropping	Mango – Intercropping (with maize and beans)
Internal Rate of Return (IRR)	23%	47%
Capital requirement for establishment, 1st year	6,455 KES	5,255 KES
Mean net income per year	10,210 KES	17,295 KES
Mean gross income per year	15,495 KES	24,296 KES

An on-going case study on mango production and economic benefits in 87 farms in the drylands (agro-ecological zones 4 and 5) of Eastern Kenya confirmed the theoretical models above. On average, a household raised almost 30,000 KES per year from mango farming (James Ngulu, pers. comm.; Table 6.2.1.4). The few female-headed households had a lower annual income than male-headed households partly because females had smaller farms and cultivated fewer mango trees than males.

Table 6.2.1.4 Mean number of mango trees, varieties, annual income from mangoes per household and % of total household income for 87 farms surveyed in Eastern Kenya in 2012.

	Cases (n)	Farm size (ac)	No. of mango trees per farm	No. of mango varieties per farm	Annual income from mango farming (KES)	Portion of income from mangoes of total income (%)
Female	9	6.8	25	2.0	22,000	29
Male	78	11.3	81	3.4	30,000	28
Total	87	10.8	75	3.3	29,600	28

In the Nuba Mountains, Sudan, 170 households (50% female-headed) were interviewed about the contribution of non-timber forest products (NTFPs), including wild fruits, to household income in 17 villages in four provinces [57]. The respondents named 20 different tree species used for food, among them 19 fruit trees species and five species whose leaves were partly or exclusively used as vegetables. For 30% of the respondents, selling NTFPs was the most important income source. In female-headed households, NTFPs contributed 70-88% of the total income in every province; in contrast, in male-headed households, they contributed only 25-33% (Figure 6.2.1.2).

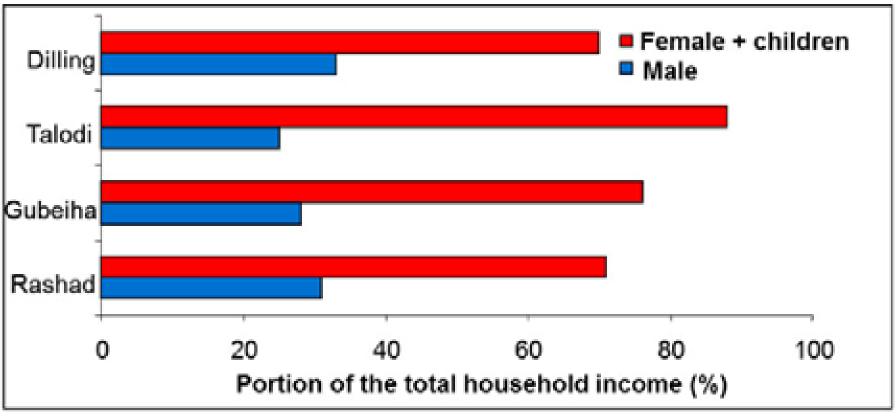


Figure 6.2.1.2 The contribution of sales of NTFPs, including wild fruits, to household income in four provinces of the Nuba Mountains, Central Sudan [57].

It thus appears that men usually undertake commercial fruit farming, while wild fruit collection, processing and marketing is largely the domain of women (see also above examples from [52] and [53]. The role of wild fruit trees is of particular importance for resilience during droughts and lean seasons – the 'hunger gap', which occurs at the beginning of the cropping season, when households have finished their grain stocks and the new crop is not yet ready for harvest. For example, Mwingi district in Eastern Kenya experiences two hunger seasons per year during which 10-25 wild fruit tree species have fruit ready for harvest; the fruit serves not only as emergency food but also to generate cash income. During the first cropping ('hunger') season (March-May) a total of 19-25 species have mature fruits, including *B. aegyptiaca* and *V. payos*, while during the second harvest season (October-December) only 10-14 have mature fruits (Source: P. Simitu, pers. comm., see Figure 6.2.1.1).

Domesticating these important wild species and promoting their cultivation on farms could play a key role in enhancing the food and nutritional security of rural communities.

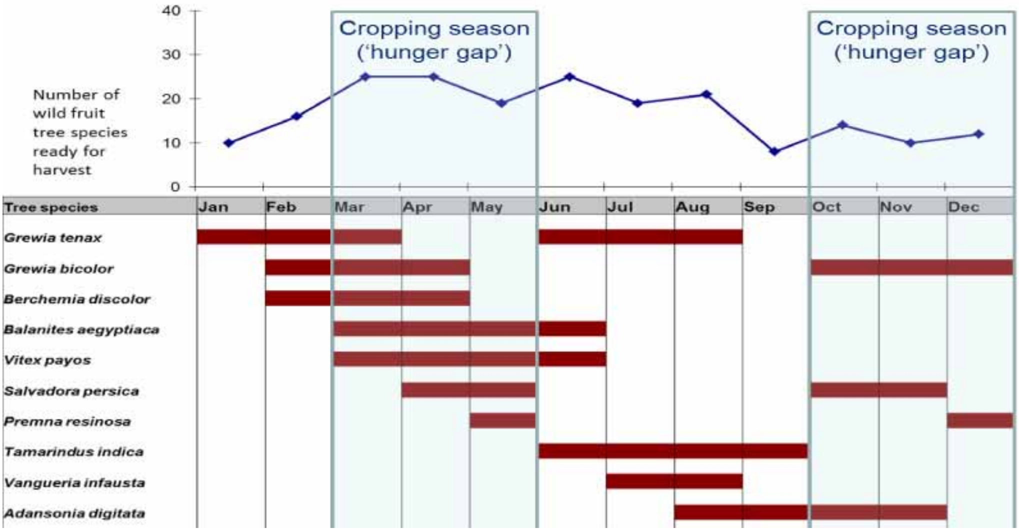


Figure 6.2.1.3 Total number of wild fruit tree species with ripe fruits per month (line graph) and harvest season (brown bars) for selected ones in Mwingi district, Eastern Kenya.

The role of policies and institutions

The value of horticulture, including fruits, for nutrition and food security, income ('farming as a business') and the national economy (earning foreign exchange) is largely acknowledged by policies and governmental as well as non-governmental institutions. Similarly, the importance of trees for maintaining production and environmental service functions of agro-ecosystems is largely recognized. In Kenya, for example, the Agricultural Act (CAP 318) on Farm Forest Rules from 2009 stipulates that every farm should have at least 10% tree cover. This offers a huge opportunity for promoting the cultivation of food trees, including wild fruit species.

However, the role of wild food trees in improving livelihoods, economic development and agro-ecosystem functions is often neglected. There is need to conduct research to assess policies that affect the domestication and adoption of wild food trees, their production, management, processing and marketing. Land and tree tenure issues, tree nursery systems and the quality of propagation material also need to be researched. Such inquiry should cover the policies of forestry and natural resource management, agriculture, public health, trade and industry, and rural development sectors. Research on the policies of the above sectors regarding wild fruit trees has been undertaken in Southern Africa [58]. However, detailed information is still lacking for Eastern Africa. Identifying gaps in legislation is a prerequisite to developing recommendations to address these gaps.

In addition, more comprehensive biophysical and socio-economic studies are needed to validate and communicate the importance of food trees for nutrition and health, income generation and rural development in Eastern Africa. Such information, together with the results of policy reviews, needs to be communicated to policy makers and governmental and non-governmental institutions. This would contribute to the development and implementation of appropriate policies to strengthen the role of food trees for improved livelihoods.

Regional variation between dryland zones

As mentioned above, huge differences often exist among regions with regard to the consumption of and value attributed to indigenous tree food products as well as their production, processing and marketing and the income that they generate. Such differences can even exist within one region, e.g. the Nuba Mountains, Sudan [57], where a remote location and poor market access resulted in wild tree products having higher importance. In Uganda, different ethnic groups made different use of desert date products, with one preferring to use leaves and the other pulp and seeds [52].

Another reason for differences in consumption, production and marketing of food tree products is related to differences in the species available and suitable for the different zones (e.g. Miombo/non-Miombo woodlands in drylands of Tanzania). Regions with different natural vegetation types will have a different food tree species composition (see maps available for Eastern Africa, developed under the VECEA project on the ICRAF website http://www.vegetationmap4africa.org/). In addition to the natural environment, there are also differences in the political and institutional environment across the drylands of Eastern Africa.

Challenges

- Lack of consumer awareness on the health benefits of regular fruit and vegetable consumption.
- Loss of the traditional nutrition systems based on local agro-biodiversity.
- Low acceptance of wild food tree products by urban consumers.
- Lack of domestication efforts and efficient seed/seedling supply systems for wild food trees.
- Low productivity of wild food trees (no improved varieties, poor tree management).
- Lack of processing facilities and poor market pathways.
- Unsustainable harvest of wild tree products and degradation of natural vegetation.
- Lack of uniformity of wild tree products, including high variability of nutrient contents.

Knowledge gaps to be addressed

- Nutrient content of lesser known wild food tree products.
- Gender- and age-disaggregated consumption data of tree foods.

- Data on the importance of wild food tree products for income generation.
- Propagation techniques for wild food trees.
- Production data and management techniques for wild food trees.
- Processing methods and value chain development for wild food tree products.
- Identification of social factors leading to low fruit and vegetable consumption.
- Identification of best agroforestry- and nutrition-based interventions to address low fruit and vegetable consumption.

6.2.2 Browse as livestock feed in the drylands

Emiru Birhane, Monicah Kinuthia and Benjamin Kibor

Shrubs and trees are an important source of livestock feeds in the drylands of Eastern Africa. Camels, goats and sheep have been browsing the leaves and bark of shrubs and trees for ages, while farmers have facilitated availability of fodder from trees and shrubs through planting. This section reviews the current and potential use of trees as a source of livestock feeds, their benefits and the resilience that they provide as well as environmental sustainability and the need for policy to promote a sustainable use.

Browse from spontaneously established trees and shrubs forms an important source of feed for millions of camels, goats and sheep in the drylands of the Eastern Africa region (Figure 6.2.2.1). While it is eaten throughout the year it contribute to livestock resilience particularly during the dry season and drought, because it remains green due to deep roots and contains water into the dry season and frequently is of high quality (Table 6.2.2.1) that may compensate nutritive deficiencies of lower quality forage derived from grasses and herbs. The nutritive value of selected trees and shrubs is further presented in table 6.2.2.2.

Figure 6.2.2.1 Browsing by camel and goats

Table 6.2.2.1 Nutritive value of two of the most dominant browse species (*A. melifera and A. nubica)* around Aba'ala, northern Ethiopia [59]

Species	Nutritive parameters						
	DM	CP	ADF	CF	%Fat	P	Mg
A. mellifera	52.255	11.564	17.199	16.808	5.765	0.138	0.467
A. nubica	30.392	23.123	21.222	17.440	13.154	0.307	0.417

Several indigenous and exotic tree and shrub species have been recognized for their potential as forage plants, and there has been a strong interest to increase the availability of tree-based fodder. *Ficus thonningii* for example is an indigenous tree species, which is planted and purposely maintained in the highlands of Ethiopia for fodder. *F. thonningii* leaves were demonstrated to be good sources of nutrients (proteins, fats, starch, fibre and minerals) and are within the recommended range for ruminant livestock growth and development [60]. The use of *F. thonningii* as supplements/substitute livestock feed to low quality grasses in the district, especially during the feed scarce periods, it serves as an alternative and needs promotion and scaling up. However the adoption of exotic tree species into pastoral dryland farming systems has been poor because of diseases and the inability of pastoralists to provide the level of management that these exotic fodder trees require [61] [62] [63].

Table 6.2.2.2 Chemical composition (g kg^{-1}DM) of some selected trees and shrubs [64]

Species	CP	NDF	ADF	ADL	Ash	Reference
Acacia albida	143	374	279	45	27	(Tanner et al. 1990)
Albizia chinensis	211	354	246		145	(Ash 1990)
Cajanus cajan	201	539	371	175		(Nsahlai et al.1995)
Calliandra calothyrsus	173	302	229	84	40	(Ahn 1990)
Chamaecytisus palmensis	178	342	235	64		(Nsahlai et al.1995)
Desmodium intortum	183	714	432	112	111	Kariuki, (1998)
Erythrina variegate	175	532	425	68		(Nsahlai et al.1995)
	264	457	343	9	91	(Rajaguru 1990)
Gliricidia sepium	183	656	357		59	(Ash 1990)
Leucaena diversifolia	308	246	114	41	75	(Siaw et al 1993)
Medicago sativa	206	426	296	72	89	(Kariuki 1998)
Sesbania sesban	356	203	108	24	94	(Siaw et al 1993)
Trifolium semipilosum	219	398	327	21	80	(Kariuki 1998)
Vernonia amygdalina	148	312	277	61		(Bonsi 1995)

CP, Crude protein; NDF, Neutral detergent fibre; ADF, Acid detergent fibre; ADL, Acid detergent lignin.

Indigenous browse plants have fewer of these problems and Le Houerou [65] reported that out of the 5000 African tree and shrub species suitable for feeding livestock in Africa, 80 had real fodder value. This probably underscores the lack of information on the value of these indigenous browse species [61]. Considering the high population of cattle and browse animals in Africa and acute shortage of the conventional livestock feed there should be another supplementary input which is easily accessible. These large populations of browse animals must depend on the feed resource within their vicinity. They feed on the indigenous tree and shrub species scattered all over the free grazing landscapes. With regard to the variety and number of species, it can be said that there is a special need for research and extension specifically focused on the identification, evaluation of nutritive value and screening of indigenous browse species.

Table 6.2.2.3 Relative multipurpose values of different browse species according to the rank given by pastoralists in Ethiopia

Scientific Name	Vernacular name	Fodder	Fuel	Shade	Drought resistance	Biomass production	Composite Rank
Acacia mellifera	Merkaeto	3.25*	5.54	3.42	1.78	10.45	4.888
Acacia nubica	Garmoita	7.24	6.08	2.32	2	1.24	3.776
Cadabarot indifola	Adangaleta	8.01	7.36	7.24	2.45	6.89	6.39
Acacia etbaica	Sekakto	3.83	1	1.24	10.11	3.24	3.884
Cordiagharaf	Mederto	1.02	2.08	4.25	10.25	12.7	6.06
Grewia erythrea	Hidaito	5.37	3.41	6.8	4.76	11.3	6.328
Commiphora spp.	Adwohadita	9.23	3.8	8.09	8.34	8.76	7.644
Acacia tortilis	Aepto	9.24	4.28	5.47	5.24	9.24	6.694
Acacia nilotica	Gessalto	7.26	9.87	5.42	1.25	2.12	5.184
Balanites aegyptiaca	Oodaito	3.24	6.7	8.24	1.45	3.12	4.55
Ziziphus spina-chrisiti	Kusraito	3.38	4.25	10.12	2.4	5.56	5.142
Grewia villosa	Hibelita	6.43	12	6.23	8.4	4.36	7.484

Results of a study in Naivasha, Kenya [64] on supplementation of dual-purpose goats on leguminous shrubs showed that both milk yield and growth increased significantly, thus improving farmers' income [64]. In addition to the indirect benefits that the people get through increased productivity from their animals other benefits are realized too (Table 6.2.2.3). For example, the average household income from *Ziziphus spina-christi* growers was significantly higher than that of non-growers. The average income gain (selling of fruits, fertility addition, browse) due to *Z. spina-christi* tree growing ranges from USD 80 to 81.21 per household per annum. Generally *Z. spina-christi* is a multipurpose tree that improves, soil nutrients, feed source and income generation to households [66]

6.2.3 Medicine and pesticides

Stepha McMullin, Parveen Anjarwalla, Samson Gwali, Mary Njenga, Ramni Jamnadass

In parts of the tropics, medicine and pesticides collected from wild trees, shrubs and plants play a vital role in the health of people, their livestock and the protection of their crops. The high proportion of the population using traditional herbal medicine (THM) is often due to lack of adequate and accessible medical treatment and based on traditional and cultural practice and preference due to perceived efficacy [67]. For example, the Kenyan medical health care system serves only 30% of the population, thus the implication is that the remaining 70% (estimated to be 21 million people) are outside of the primary health care system and may rely on and use traditional forms of health care such as THM and the use of medicinal tree and shrub material [68]. Other factors contributing to the high use of THM in Eastern Africa include population increase, growing urbanization, poverty, disease epidemics especially malaria and tuberculosis, the emergence of chronic conditions, and environmental instabilities [69]. Many of these factors are relevant to the drylands, which constitute 69% of the region and lag behind in terms of access to health care for humans and livestock. Medicines and pesticides from trees and shrubs have significant potential, but poor scientific evaluation, validation and documentation impede wider use [70].

The application of trees and shrubs as a source of medicine for livestock is known as EVM or ethno-veterinary medicine [71, 72]. There is high demand for EVM because of the significant number of pastoralists and their livestock in the dryland areas, and due to the marginal cost and the ease of administration. Practically, this is the most feasible solution available to many livestock owners in the drylands of Eastern Africa due to its availability and cost-effectiveness rather than the poor accessibility to extension services.

Region-specific information on the use of EVM has been reported for Samburu, Kenya [72, 73] [74] and the Karamoja in Uganda [75]. Tree species used in EVM in Samburu include *Myrsine africana, Albizia anthelmintica, Hildebrandti asepalosa, Hagenia abyssinica, Annona squamosa, Dodonea angustifolia* and *Azadirachta indica.* Commonly used EVM species in the Karamoja include *Balanites aegyptiaca, Carissa spinarum, Warburgia ugandensis* and *Harrisonia abyssinica.* Opiro [76] reported use of *Senna didymobotrya* and *Kigelia africana* for removal of ticks from livestock.

African farmers have used pesticidal plants to protect their field crops, stored grains and livestock from pest damage. Botanical pesticides kill and repel pests, affect insect growth and development, have antifeedant and arrestant effects and have antifungal, antiviral and antibacterial properties against pathogens[77, 78]. Examples of pesticidal plants in arid and semi-arid regions include *Euphorbia tirucalli, Azadirachta indica, Bobgunnia madagascariensis* and *Aloe ferox.* Extracts from the neem tree (*Azadirachta indica*) are widely used, while pyrethrum serves export markets [79]. Pesticidal plants are environmentally benign, relatively safe and cost-effective compared to synthetic pesticides. In addition to the benefits of their use by smallholders, farmers can cultivate and sell these plants to generate income and provide a sustainable and environmentally cost-effective form of pest management. To improve the use and up-take of pesticidal plants, the development of a value-chain based on indigenous knowledge and use is recommended by [80]. However, to date, little progress has been made to develop appropriate policies to promote their use on a wider scale.

Herbal medicines based on traditional knowledge have an estimated global market value of USD 60 billion [49]. Even a fraction of this market is economically appealing to Africa. Worldwide, an estimated 70,000 medicinal tree and plant species are used in THM trade [81, 82]. Actors involved in the THM supply chain include collectors, traders and processors and while commercialisation is necessary, it's also potentially harmful to farmers and rural people [83, 84]. If commercialization expands to the point that outsiders with capital to invest develop large-scale monoculture plantations to supply export markets, large plantations can distort market forces and alter supply and demand and therefore prices [84]. Without commercialization however, the market for products is small and the opportunity does not exist for rural people to generate income. A strategy to address sustainable use and supply of species, and to support conservation of in-demand species is necessary to promote their domestication and cultivation on smallholder farms for better economic benefits. Small-scale tree cultivation and home-gardens require low economic inputs and can be a response to declining local stocks, and provide an additional income for rural households and communities while supplying regional markets [84].

Species-specific trade networks for medicinal plant products exist across national boundaries [85]. Regional trade in medicinal tree species material has been recorded in Eastern Africa between Tanzania and Kenya, [86]. The regional movement of medicinal tree and shrub material is probably more extensive than has been documented, particularly between border areas. Medicinal plant products on the market in Eastern Africa are based on formulations in the form of crudely chopped material, ground powder, syrups and ointments. These are sold directly to consumers through herbal clinics, traditional medicine practitioners and open air markets. The use of THM does not reach its potential due to its informal status in the collection, processing and marketing that results in inconsistent supply of material and low confidence of its quality and safety for use. The commercial trade of high value medicinal products sourced from natural populations (bush, savanna, forest) drives intensified production and specialization by the actors involved in the supply chain. A study by Muriuki et al., [87] found that material traded in increasingly formalised settings in Kenya (herbal clinics, end product dealers and processors of medicinal material) was mainly sourced from the wild but some of it from farms. A further study in Kenya [86] found that medicinal tree and shrub material traded in the open air markets was almost exclusively sourced from the wild and natural populations of species. This was also found to be the case in Ethiopia [88].

Unlimited trade and unconstrained collection of medicinal material from trees is negatively affecting the populations of trees supplying these valuable goods [89]. Hamilton [90] considered that globally, almost one-third of medicinal plant species could become extinct. The greatest losses might occur in arid and semi-arid areas where tree populations are also decimated by other factors such as wood consumption, grazing, erosion, expansion of agricultural land and climate change [91]. Muriuki [92] found that, despite a higher diversity of medicinal tree species in the drylands compared to neighbouring humid lands, herbalists preferred collecting trees from drylands even where similar species exist in humid lands which could lead to fast degradation of the dryland resources. Given this demand, and the challenges associated with the establishment of trees in drylands, there is a need to consider a number of options. This includes, first, to sustainably manage the collection of medicinal material from wild populations and where scarcity sets in, introduce the cultivation of medicinal species in on-farm agroforestry systems. An additional initiative for consideration would be to encourage farmer-managed natural regeneration of high value medicinal tree and shrub species through participatory approaches (see chapter 7, section 7.4).

Tree and shrub based medicine is a mainstay particularly in households where they are the only source of cash income [93, 94]. The production, post-harvest handling, and marketing of medicinal trees and shrubs significantly contribute to the cash income of the marginalised rural poor, such as women, for whom this is a socially acceptable employment and income-generating activity [89, 95]. Tree and shrub based medicine also provides resilience when it generates income and employment to drylands communities during the dry season and drought. With the risk of overutilization there are limitations however to the social security that tree-based medicine can provide, and agendas promoting tree and shrub based medicine as a pathway out of poverty should go hand in hand with agendas to manage the trees sustainably. Furthermore competing uses for timber, charcoal and construction materials have put medicinal tree species under threat, increasing their scarcity.

Recent efforts to document THM knowledge through ethno-botany provide a welcome basis for up-scaling medicinal and pesticidal tree species as a pathway to improve income generation for communities in the drylands. This knowledge provides a repository on which a pharmacopoeia may be developed in addition to species-specific conservation strategies. For example the National Museums of Kenya maintains the Kenya Resource Center for Indigenous Knowledge (KENRIK) database, which provides basic information on several Kenyan medicinal plants [96]. However herbal medicine in the drylands is largely processed through traditional methods and the poor infrastructure (both physical and communication) hampers growth of the industry because the poor communities cannot access modern technologies and market information. The knowledge is also accessed free-of-charge and local communities' entitlements to relevant intellectual property rights are generally not recognized by other interested parties [97]. This has led to some resistance by dryland community experts to share knowledge in ethno-botanical surveys. This has further repercussions for maintaining and documenting local indigenous knowledge related to medicinal and pesticidal species.

Box 6.2.3.1 Examples of trees and shrubs found in Eastern African drylands and their medicinal purposes

Albizia anthelmintica commonly occurs in deciduous or evergreen bushland and scrubland especially along seasonal rivers and on termite-mound clump thickets. Its geographic distribution includes Botswana, Kenya, Namibia, Somalia, South Africa, Swaziland, Tanzania and Uganda. It is used as a de-wormer and a purgative and for the treatment of some sexually transmitted diseases.

Aloe ferox Mill is distributed in tropics and sub tropics and while it is cultivated in Kenya, it grows in the semi-arid open plains to rocky mountain slopes in South Africa. In humans it is used for skin regeneration, it reduces swelling and pain of arthritis and rheumatism. It repels insects when planted as a live fence. In cattle it treats jaundice, red water and expels worms.

Azadirachta indica (neem). The essential uses of the neem tree are in the control of agricultural insect pests and human medicine for insect bites, malaria and skin infection. This tree crop is now also becoming popular in the drylands of Tigray, Afar, and Somali regions of Ethiopia. In Kenya, the promotion of neem trees was initiated due to its properties in controlling hundreds of insect pests of crops and of public health importance. From 1991 to 2000, ICIPE conducted a USD $1.79M neem awareness project in sub-Saharan Africa funded by the Finnish government and UNEP. The project contributed to mitigating rural poverty by education and dissemination of knowledge on neem technology for better plant, animal, human and environmental health. Large scale neem planting was done by the project in 75 schools in Suba and neighbouring districts in Kenya, Adjumani in Northern Uganda, Kwimba Reforestation Project in Mwanza, Tanzania and in many homesteads in Kenya. Future plans of the project include a 'Neem-health and Wealth' project which will focus on developing neem extracts for medicinal, veterinary and plant health uses. http://www.fao.org/DOCREP/003/AB569E/AB569E00.HTM.

Carissa edulisis used to treat malaria, typhoid fever, and chest conditions such as cough, asthma, fibroids, arthritis, low immunity, cancer, allergies, blood pressure, stroke, tumour, syphilis, infertility, herpes simplex and vivax, vaginal candidiasis, diabetes. Carissa edulis, also known as the 'magic herb,' has encouraged thousands of people to flock to remote Loliondo village in Tanzania to seek treatment. This species was identified by Kenyan scientists four years ago as a cure for a drug-resistant strain of a sexually transmitted disease.

Euphorbia tirucalli is used as treatment for toothache, snake bites, asthma and as pesticide against aphids, mosquitoes, bacteria and mollusc. It is normally found in dry bushland thickets and naturalizes easily in brushwood, open woodland and grassland up to 2 000 m. Its geographic distribution includes Angola, Eritrea, Ethiopia, Kenya, Malawi, Mauritius, Rwanda, Senegal, Sudan, Tanzania, Uganda, Zanzibar

Moringa stenopetala (Bak.) is native to India and cultivated throughout the tropics especially in arid areas. The species is quite drought resistant. In southern Ethiopia, it has been found in areas of mean annual rainfall ranging from 500-1400mm. Its geographic distribution includes Kenya, Ethiopia and Somalia. Many parts of the plant have been used in medicinal preparations especially the roots and seeds. The crushed seeds can also be used for cleaning water for drinking. The leaves and fruits are eaten as vegetables and are rich in proteins, calcium, and iron, phosphorous as well as vitamins A and C.

Source: Maundu P. and Tengnas T. (Eds). 2005 and AgroForesTree Database,

http://www.worldagroforestrycentre.org/sea/products/afdbases/af/asp/SpeciesInfo.asp?SpID=1745

Strengthening rural institutions in the drylands to manage knowledge repositories and species conservation strategies is necessary as well as to contribute towards benefit sharing for the communities who rely on and use these resources. Grassroot and local government institutions can help safeguard community heritage, intellectual property as well as secure patents and trademarks on indigenous knowledge and technology related to medicinal (human and livestock) and pesticidal species.

There are various policies and institutions supporting the collection, processing and marketing of tree-based medicine. The following policies and institutions are in place in Uganda. The Natural Chemotherapeutic Research Institute (NCRI) promotes the use of herbal medicines as an alternative public health strategy, and provides laboratory testing services for herbal formulations and advisory services to herbal enterprises. The Uganda National Export Strategy (2009-)) identifies medicine from natural plants for export trade development. The Uganda National Drug Authority (NDA) regulates the registration and certification of herbal formulations. The collection of herbal material from government protected areas is controlled through sectoral regulatory frameworks implemented under the Wildlife and Forestry Acts. Yet, while policies and institutions exist they are not always implemented to their intended purpose and there is thus a need to monitor and enhance the effectiveness of their implementation. For instance in Kenya THM was officially recognized in the 1990's and the patent law revised to include THM in 1999 but few developments have been seen in the regulation of the practice since then. A draft policy to regulate the practice of THM with a view to incorporating the herbal practitioners is also yet to be enacted.

6.2.4 Oils from trees in Eastern Africa drylands

Alice Muchugi, Clement Okia, Joyce Chege, Francis Omujal

Introduction

The drylands of Eastern Africa are characterized by environmental conditions that pose significant challenges to economic development but their unique natural potential could be tapped for poverty alleviation. Among the region's natural flora are several oil producing tree species that when properly managed have high commercial and economic potential to enhance community's resilience during extreme weather conditions. The oil products from these trees can be classified into three major groups according to their use (i) human dietary (ii) medicine and cosmetics and (iii) biofuels. Table 6.2.4.1 provides a summary of indigenous tree species with a potential for oil production found in the Eastern Africa drylands. This list is however not exhaustive. The list includes some introduced species such as *Jatropha curcas, Azadirachta indica* and *Aleurites moloccana* that have become naturalized in the region. Other oil producing tree species found within the Eastern Africa drylands with potential for exploitation include *Cephalocroton cordofanus, Moringa stenopetala, Schinzio phytonrautanenii* and *Tarchonanthus camphoratus.*

Local and commercial use of oil trees

There is evidence of use of oil tree products by the local communities within the species habitat in Eastern Africa (Table 6.2.4.1). Other examples of oil products of dryland tree species can be found on (http://phytotrade.com). Economic returns from the processed oil products can be quite high especially in the cosmetic industry. In the case of *Sclerocarya birrea* (marula) in Namibia, with access to new markets, approximately 2,000 rural farmers producing marula were receiving USD 2.35 per kilogram of marula by 2010 (http://phytotrade.com). There is potential in Eastern Africa too as shown by a tree oil project in Kenya involving cultivation of *Melaleuca alternifolia* (tea tree) where it earned 540 small-scale farmers USD 5.45 per kilogram of tea tree leaves (total of USD 1.8 million from 330,000 kg [98]. The Kenya and Namibia projects as well as the QualiTree project in Mali and Burkina Faso (http://www.qualitree.neri.dk/) are good examples of interventions in the tree oil production that can be undertaken to economically benefit the rural communities in Eastern Africa.

Use of dryland tree species for biofuel offers an alternative to one of the major challenges encountered as developing countries invest in alternative energy sources. This is because most preferred feedstock are also used as human food and are grown in high potential areas where land is also limiting [99, 100]. The prospects of exploiting *Croton megalocarpus* as a biofuel is promising as oil quality is comparable to other biofuel trees, jatropha and palm oil [101-103]. However, despite the promising outlook, there is need to established biofuel value chain in Eastern Africa, as evidenced from failed projects [104].

Commercial production of shea butter and shea oil

It is estimated that the cosmetic and pharmaceutical industries mainly in Europe, Asia and America consume between 2,000- 8000 tons of shea butter each year [105]. However, the market supply of shea nuts and shea butter oil from Eastern Africa, are considerably less than in West Africa and there are no statistics available for export in Eastern Africa. The current market sector can be described as almost entirely subsistence in nature with low levels of collection and consumption.

Table 6.2.4.1 Oil-producing trees species of the Eastern Africa drylands

Species and its occurrence	Main oil use	Brief notes on the oil characteristics
Adansonia digitata (Baobab) Found in the hot, dry savannas of sub-Saharan Africa	Cosmetic and pharmaceutical industry	Seed kernel oil content from 30% to 68% with equal amounts of saturated (33%), mono-unsaturated (36%) and poly-unsaturated (31%) fatty acids, including palmitic (18.0 - 30.0%); stearic (2.0 - 9.0%); arachidic (< 2.0 %) oleic (30.0 - 42.0%); linoleic (20.0 - 35.0%) and alpha linoleic acid (1.0 - 3.0%).
Aleurites moluccana. Introduced in tropical drylands and grown on a limited scale in DR Congo, Tanzania, Uganda, the Comoros, Madagascar, and South Africa.	Cosmetics, industrial (paints, varnishes, linoleum, soap, wood preservation), illumination and medicine (mild purgative, embrocation for sciatica, against hair loss).	Cold-pressed oil is pale yellow, with agreeable smell. When left to stand, it dries into a thin frosty film. The fatty acid composition of the oil is: palmitic acid 5–9%, stearic acid 2–7%, oleic acid 11–35%, linoleic acid 34–49%, linolenic acid 21–35%.
Balanites aegyptiaca (Desert date). Distributed through much of dryland Africa	Food cooking, pharmaceutical and cosmetic, biodiesel	Seed kernel oil content 50%, consisting of palmitic (15.5%), stearic (19.01%), oleic (25.74%), and linoleic acid (39.85%). Medical potential as source for the manufacture of cortisone and corticosteroid drugs. Biodiesel meets international biodiesel standards. It is reported to have a composition of triglycerides of mainly C16:0 and C18:0 saturated and unsaturated fatty acids, with a very high content of linoleic and oleic acids (65.59%); further contains saponins which reduce the rate of corrosion and improve engine performance.
Croton megalocarpus occurs in Burundi, Democratic Republic of Congo, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda	Bio-fuel	Seeds have an oil content of about 30% and a protein content of about 50%. The oil has purgative activity and also showed Epstein-Barr virus activating potency. The annual seed yield per tree is of the order of 25–40 kg, average composition of 30%–32% oil
***Jatropha curcas*.** Thought to originate in Mexico or neighbouring parts of Central America, It was distributed all over the world by the seafarers and is now naturalized throughout the tropics and subtropics.	Biofuel, Traditionally used for soap production and as purgative and to expel internal parasites, an ingredient of hair conditioners, manufacture of candles and soap, as lamp oil and as cooking fuel.	Fat content of whole seeds is 32–45%, containing palmitic 3.5–15.6%, stearic 6.7–7.5%, oleic 34.3–46.3%, linoleic 30.8–43.1%, and linolenic acid 0.2%. Depending on the origin, either the oleic or linoleic acid content is higher. The bio-fuel produced after trans-esterification of the oil has characteristics similar to petro-diesel. The energy balance (the total energy inputs into the crop: the energy output) of jatropha bio-fuel is estimated at 1: 4–5, which is considerably better than for rapeseed (Canola) oil.
***Moringa oleifera*.** Indigenous in India and Pakistan. Introduced throughout the tropics and subtropics and has become naturalized in many African countries.	Food-for cooking Cosmetics-hairdressing, to make soap and perfume industry as a base for fragrant volatile compounds.	The dry seeds contain on average: protein 29%, fibre 7.5% and oil 36–42%. Fatty acid composition is; oleic acid 65–75%, behenic acid 9%, palmitic acid 9%, stearic acid 7% and small amounts of lignoceric acid and myristic acid. The oil is clear and odourless and does not become rancid quickly.

Species and its occurrence	Main oil use	Brief notes on the oil characteristics
Ricinus communis Indigenous to north-eastern tropical Africa. It naturalizes easily and grows in many areas. It is now widely cultivated in drier areas of the tropics and subtropics and in many temperate areas with a hot summer.	Biodiesel/Lubricant Industrial-crumb-rubber manufacturing, anti-stick agent for candy moulds plasticizer in the coating industry, disperser for dyes and as filler in cosmetics, wetting agent in dyeing cotton and linen fabrics, defoaming agent in the sugar industry.	The oil is non-drying, viscous, nearly colourless, transparent with characteristic odour and taste. It has the highest viscosity of all vegetable oils; ricinoleic acid, which makes up about 90% of the fatty acids of the oil, renders the special properties to the oil. Other fatty acids include: palmitic acid (2%), stearic acid (1%), oleic acid (7%) and linoleic acid (3%). Dehydration of castor oil can yield a quick-drying oil with properties comparable to tung oil and linseed oil. This is used in paints, varnishes, waxes and epoxy resins. Blown oil, i.e. oil that is oxidized and partially polymerized is a major component of hydraulic fluids. In inks, it is used to reduce water pick up and improve drying characteristics.
Sclerocarya birrea (Marula) Indigenous to the Miombo woodlands of Southern Africa, the Sudano-Sahelian range of East and West Africa, and Madagascar.	Cosmetic, food and health care products.	Marula oil contains a large proportion of monounsaturated fatty acids and natural antioxidants which make the oil very stable. The fatty acid composition of marula oil includes Oleic acid (70-78%), Linoleic acid (4.0-7.0 %), Alpha-linolenic acid (0.1-0.7 %), Palmitic acid (9-12%), Stearic acid (5.0-8.0 %), Arachidonic acid (0.3-0.7 %). Tocopherols, sterols and flavonoids, with antioxidant action. Being ten times more resistant to oxidation than olive oil, it is one of the most stable natural oils in the world.
***Trichilia emetica*.** Widely distributed in tropical Africa and occurs from Senegal east to Eritrea and south to South Africa. It also occurs naturally in Yemen and has been introduced many parts of the world.	Food-cooking oil	The seed of *Trichilia emetica* yields two kinds of oil: 'mafura oil' from the fleshy seed envelope (sarcotesta) and 'mafura butter', also called 'mafura tallow', from the kernel. Per 100 g, the envelope of the seed contains 35–60 g oil, the kernel 60–65 g fat. The fatty acid composition of the fat is: palmitic acid 34%, stearic acid 3%, oleic acid 51%, linoleic acid 11% and linolenic acid 1%; another analysis indicates: myristic acid 1%, palmitic acid 53%, stearic acid 2%, oleic acid 28%, linoleic acid 16%, linolenic acid 0.3%.
***Vitellaria paradoxa*.** (Shea butter) Indigenous to the Guinea and Sudan savanna zone [from Senegal to Sudan, and to western Ethiopia and Uganda]	Cosmetic, food-cooking/baking fat and margarine.	Shea butter from fresh seeds is white, odourless and of high quality. The approximate chemical composition of the kernel per 100 g dry matter is: fat 31–62 g, protein 7–9 g, carbohydrate 31–38 g, unsaponifiable matter 2.5–12 g. The fatty acid composition of shea butter is approximately: palmitic 4–8%, stearic 31–45%, oleic 43–56%, linoleic 4–8%, and arachidic acid 1–2%.

Source: [106]

The development of shea butter trade in Uganda for export started in 1992 under the Shea project for local conservation. Several factors including, limited awareness on the value of shea butter, high consumption of shea butter oil at household as food and inadequate local and international market information have contributed to low consumption of shea butter [107]. About half of shea butter produced in Uganda is consumed at household or sold in local markets. It is estimated that annual shea kernel production in Uganda ranges from 30,000 to 150,000tons [108]. However, Uganda export is far below the export of Ghana and Burkina Faso. The other half is exported to USA, Europe and Asian countries by organizations such as KFP/KM International Trade, NOGAMU – National Organic Agriculture Movement of Uganda, The Shea Project-COVOL, CREAM– Community Organization for Rural Enterprise Activity Management, Guru Nanak Oil Mil - GNOM Inc. and Nilo Beauty Products.

The price of shea butter processed by either local traditional boiling or cold pressed has kept increasing in Uganda. The price of one kg of cold pressed shea butter in the local market in Uganda has risen from USD 1.5 in 2010 to about USD 6.5 in 2012. However, the cold pressed shea butter from Uganda in the US market has been reported to sell at USD 60.0 per kg, far much higher than the shea butter oil from West Africa, because of its quality attributes [108] [108]. Shea butter oil from Uganda has high levels of unsaturated fat, oleic and linoleic acids. See the case study (Chapter 7 section 7.6) that illustrates the local and commercial utilization of shea trees in Uganda.

Policy issues relating to oil tree species uses and development

The policy options and challenges for tree products from dryland areas of Eastern Africa are well summarized in a 2005 UNDP study [97]. Products evaluated in the study include an oil-producing tree *Jatropha curcas*. The Eastern Africa countries have enacted policies in support for the development of the biofuel industry such as Energy Policy for Rwanda (2004); Kenya Energy Policy (2006) and the Bio-diesel Strategy Paper (2009); Energy Advisory Board, Uganda. Key issues that may need intervention in the oil trees development in Eastern Africa drylands include tree genetic resources management and improvement to ensure sustainable oil production as well as value addition to oil products and development of product markets.

6.2.5 Trees for construction materials

Sammy Carsan, Daniel Nyamai, Esther Karanja and Ramni Jamnadass

Local trees are primary sources of construction materials in the drylands of Eastern Africa. Data on the actual demand for construction wood is unavailable, as most of it is sourced locally. Probably the vast majority of the demand is for building traditional huts, livestock *kraals* and fences around crop-fields. The rest may be used for building lodges, hotels and houses in urban centres. Some of it is exported. For instance, a once common dryland species like *Dalbergia melanoxylon* that provides high quality wood for carvings and furniture is over-exploited throughout Eastern Africa. There is a growing market for sawn wood, timber and wood carving material. These are mainly sourced from forests in more humid zones. For construction wood, demand for species such as neem, juniperus, date palm (*Phoenix dactylifera*) is very high as they are known to resist insect attack and decay [109].

Figure 6.2.5.1 Left: Felling a *Melia volkensii* tree in Kitui; **Right**: View from the entrance of a livestock *kraal* consisting of branches of locally sourced trees (*Commiphora* species).

The supply of construction wood is under pressure and climate variability and change may have an impact on the distribution of trees in the drylands [97]. Opportunities to supply construction wood from dryland forestry and agroforestry are significant given the availability of inexpensive land and of suitable tree species. Where construction wood is in short supply, users, especially in urban centres, turn to Eucalyptus as a substitute as it is widely available. *Melia volkensii* is a promising tree for cultivation in the arid and semi-arid zones of Eastern Africa as it coppices well and is used for construction and furniture-making [110].

Screening of indigenous timber species and developing technologies for domestication is therefore an important research and development activity that can support production of over-exploited timber species. In addition to considerations for wood, choice of species must be guided by their adaptability to local soil conditions, drought resistance, tolerance to salinity, ease of planting, rapid growth, and even production of animal forage. Research has already generated valuable knowledge on growth and management of some of the species and their wood characteristics, as shown in Table 6.2.5.1.

Rural communities benefit from construction wood cut from drylands in many ways:

- Access to low cost materials to build houses and fence their land, providing essential security.
- Resilience against extreme weather conditions, for instance by providing materials to re-build houses destroyed by floods.
- Where markets are accessible, they also benefit from income generated through sale of construction materials.

Table 6.2.5.1 Summary of important timber species and their characteristics

Species	Wood characteristics
Melia volkensii	Easy to saw and work on and seasons well without deformation. It is pale-red to pale brown, resemble mahogany and course textured with straight grains. Wood is moderately heavy with density of 0.63g/cm^3 and durable. The timber is popular and suitable for furniture/ joinery and interior panelling.
Terminalia brownii	Easy to saw and work on and seasons very well without degrade. Wood is yellowish brown. Light with density of 0.80 g/cm^3. Durable even when in contact with the ground and is termite resistant. Used in construction, wood carving, furniture/ joinery, tool handles, carving and poles/posts.
Terminalia spinosa	Easy to saw, work and season well without degrade. Heartwood is dark brown. Very heavy and strong with density of 1.10g/cm^3 and MOR of 115 Mpa respectively. Very resistant to termites, ground contact and marine bores. It is used in poles/posts, furniture/joinery, construction of houses, dhow and boat keels.
Terminalia prunoides	Easy to saw but hard to work with hand tools. Seasons well without degrade. Very heavy with density of 0.89 g/cm^3 and very strong with MOR of 128 Mpa. Durable in ground contact and is resistant to marine and borers and termites. It is used in poles/posts, furniture/joinery, construction of dhow and boat and/or their masts, furniture/joinery and carving.
Cassia siamea	Cream sapwood with black heartwood. It has straight grain, even textured and moderately heavy with density of 0.63g/cm^3. The heartwood is moderately durable and the uses are in veneer/plywood production, general construction and poles.
Azadirachta indica	Easily sawn and seasons well with minor end checks. The sapwood is whitish grey while the heartwood is reddish brown. A moderately heavy wood with density of 0.70g/cm^3. It is a strong wood with MOR of 86 Mpa and crushing strength value is 59 Mpa. It is durable. The uses are in furniture/ joinery, wood carving, poles, wood fuel, shade and medicinal.
Terminalia kilimandscharica	Easy to saw and seasons with little degrade though the pith is liable to splitting. The sapwood is pale pink while heartwood is pale yellow to green brown. It has medium texture and interlocking grains. It is heavy with density of 0.80g/cm^3. Moderately strong with MOR value of 103 Mpa and crushing strength value of 70 Mpa. It is used in heavy construction, furniture/joinery and carving.
Cordia sinensis	Difficult to saw but easy to work. Sapwood is light brown while the heartwood is chocolate brown. Fine and even textured with straight or slightly wavy grains. It is heavy with density of 0.80g/cm^3 and hard with Janka hardness value of 08.9 kN. Used for building, carving and furniture/joinery.
Dalbergia melanoxylon	Is a high quality timber species with a density of 1.25g/cm^3 and MOR of 135 Mpa. It is most preferred for carving, construction and furniture. Owing to its high demand, especially in carving industry it is threatened due to over-exploitation.

MOR = Modulus of Rupture; Mpa=megapascal; kN = kilonewtons

Given the need to promote conservation in fragile dryland environments, questions exist on the sustainability of utilization wood for construction. At first sight, there appears little reason for concern because local construction demands are low in proportion to the total volume of wood extracted from drylands, with the largest fraction being taken out for the production of wood fuel and charcoal. A heavier toll on trees emerges when construction wood is derived from trunks. The collection of construction wood is high around settlements and over-exploitation for some species is common resulting in severe reduction of tree densities. Luckily, woody trees possess all kinds of adaptation to their environment and in particular to drought. Many trees in the dryland zones reproduce vegetatively. This helps the species perpetuate themselves and to resist fire and heavy browsing. Many species such as *Acacia seyal, Faidherbia albida, Azadirachta indica, Cassia simea*, and *Tamarindus indica* can also coppice well. Others grow easily from cuttings for instance when established as hedges or living fences, e.g. *Commiphora sp., Boswellia paprifera,* and *Euphorbia sp.* The integration of woody plants and fast-growing trees for better, more intense and above all sustained yields is therefore a key element of good policies on managing drylands and combating desertification.

There are however socio-political challenges to the development of woody perennials in the drylands, as the majority of lands are public (government controlled) property or owned collectively. Issues of gender bias persist because men dominate the trade in construction wood whereas women commonly lead the construction of traditional huts. To develop successful wood production enterprises it is important to pass on the responsibility to well-intentioned users. Greater public awareness is needed on the importance of maintaining productive tree cover and how to develop sustainable enterprise from it. There are few dedicated national-level policies that consider the role of trees in drylands for construction (though they certainly exist at local levels). Broader natural resource management and forest policies that foster the planting/protection of trees and the conservation of tree cover are required to ensure the availability to tree resources that can secure multiple benefits that construction wood provides to dryland inhabitants. Broader awareness on the role (and true economic value) of trees for construction will help close the policy gap affecting the development of these important construction resources. More comprehensive information on the significance of tree species for construction could be a first step to resolving this gap.

6.2.6 Wood fuel

Miyuki Iiyama, Mary Njenga, Jan de Leeuw, Josephat Wagura, Nicholas Syano, Benjamin Gama, Anthony A. Kimaro, Henry Neufeldt, Philip Dobie, Ramni Jamnadass

Wood has been used as fuel for millennia, meeting humanity's basic needs for cooking, boiling water, lighting and heating [111]. Today wood fuel, namely firewood and charcoal, accounts for approximately 10% of global energy supply, but wood fuels dominate energy provision in many parts of the developing world. Especially, the inhabitants of sub-Saharan Africa (SSA) benefit significantly from wood fuel [112]. The per capita wood fuel consumption of 0.69 m^3/year in SSA in 2011 was 2.5 times higher than the global average of 0.27 m^3/year (own calculation). Over 90% of the overall population of 852 million and virtually 100% of the 535 million rural residents rely on wood fuel for energy [113].

There are distinctive geographic and sectoral demand and supply patterns for firewood and charcoal in SSA. (a) Firewood serves mostly rural subsistence needs on one hand and (b) commercial/institutional demand on the other hand, while (c) charcoal demand is highly associated with urbanization primarily met by unsustainable supply from drylands. Although officially discouraged under national law and the UN Security Council, charcoal export to Gulf countries is the biggest source of foreign exchange for Somalia [114]. This should reflect the different scenarios where in some countries it is illegal while in others like Kenya, Sudan and Namibia it is legal. In Sudan (North) it is sustainably produced while in many other countries it is unsustainably produced.

Firewood supply for rural subsistence demand

Firewood, although often regarded as an inferior energy source, is widely used for domestic purposes in rural areas [115] and most cities [116]. Firewood for domestic use is mostly from farm or dead wood from non-forest sources [117]. Once wood is exhausted on or near the farm, the scarcity of energy drives the women and children of the households to spend more time collecting wood fuel and burdens them with carrying heavy loads. They may also resort to using inferior and unhealthier alternative fuel sources such as plastic waste, not cooking food properly thus suffering from malnutrition, and using cow dung or crop residues which are otherwise used as fertilizer [118].

Firewood supply for commercial/institutional demand

Firewood is also in high commercial and institutional demand by estates (tea, tobacco factories), businesses (breweries, bakeries) and local institutions (schools, prisons and road construction companies). For example, 13kg of wood is required per 1kg of cured tobacco in Tabora, Tanzania [119, 120], while one school requires 200-500m^3 of firewood per year in Laikipia, Kenya (estimated by J Wagura). Some estates and institutions establish plantations and nurseries to provide seedlings to surrounding communities to source wood in proximity. However, excess demand has exerted pressure on dryland forests where wood supply is dependent on natural regeneration. In Tabora, Tanzania, tobacco farmers gather 30% of the wood from private and 70% from general lands and forest reserves, mainly indigenous tree species of the miombo woodlands (e.g., *Brachystegia speciformis*) [120]. To meet the wood demand for tobacco curing, 140,000 ha of miombo woodlands were cleared annually, accounting for 4-26% of the deforestation in the miombo eco-region [121, 122]. However, studies suggest that such high deforestation rates in the region could be reduced substantially through on-farm wood supply by using woodlots or short rotation plantations to meet the increasing demand of wood for domestic and/or agro-processing industries [123, 124]. About 2,000 ha and 8,000 ha of native forests cleared annually in Morogoro and Tabora regions of Tanzania, respectively could be avoided through on-farm wood supply from this technology [119, 124]. Experience from Kenya and Tanzania suggests woodlots and other agroforestry practices are holding promise to meet household fuelwood demand for up to 16 years [123, 125-127].

Rural charcoal supply to meet urban household and commercial energy demand
Charcoal is preferred in urban areas due to its higher energy density, lower transport costs and relative clean [128] [115, 128, 129], although it emits more carbon monoxide [130]. In Eastern Africa, 82%, 80% and 70% of urban households in Kenya, Tanzania and Ethiopia respectively, rely on it [131-134]. With urbanization, the market share of charcoal is steadily growing [115, 135] and average annual consumption growth rates for 2000 to 2010 was 3% for charcoal (against 1% for firewood), exceeding the annual population growth rate of 2.6%.

Figure 6.2.6.1 Piles of fire-wood on the roadside awaiting transportation to Addis Ababa, Ethiopia

Figure 6.2.6.2 One of the numerous roadside charcoal vendors in Nairobi, Kenya

Figure 6.2.6.3 Earth mound charcoal kiln, with the conversion efficiency as low as 8% in Mutomo, Kenya

In the SSA context, rural charcoal supply to meet urban household and commercial energy demand is one of the major causes of forest degradation in drylands, as a by-product of land use change converting forest to cropland [115, 133]. Firstly, charcoal production depends on selective felling of live trees in forests and woodlands, leading to biodiversity loss [117, 133, 136, 137]. Secondly, more wood is required to produce a unit of charcoal than firewood as the majority of the producers use traditional earth kilns (Figure 6.2.6.3) with the wood to charcoal conversion efficiency of 8 to 20%, while improved kilns attain over 30% efficiency [133, 138]. The negative impacts of charcoal production on dryland forest and woodlands are likely to increase with urbanization and population growth [115, 128, 137, 139].

There is tension between the increased demand for charcoal and the sustainability of wood fuel provisioning from African drylands [128]. Options to improve sustainability include promoting more efficient charcoal production and consumption and the sustainable supply in the framework of enabling policies. More efficient kilns and improved cooking stoves will reduce the amount of wood required per unit of charcoal produced, with properly drying wood before use [128, 140, 141]. The improved cooking stoves will also reduce air pollution provided the stoves are installed and maintained properly [111, 113]. Changes in land management are also required to create sustainable charcoal supply systems rather than the 'one-off' harvesting of wood [141]. With improved management, biomass carbon stocks in forests may recover and be maintained along with charcoal production [133, 142]. Agroforestry plays an important role in making charcoal supply more sustainable by reducing pressure on harvesting wood from natural tree stands through increased wood supply on farm [127, 143]. Other options include charcoal briquetting of agricultural and tree by-products, which provide fuel of high quality [144] and producing charcoal from invasive tree species such as *Prosopis juliflora*. In the West African Sahel and dry savanna of Burkina Faso, managing resprouting trees after selective cutting is ideally suited for fuelwood and charcoal production because of the natural ability of many indigenous species to regenerate vegetatively [145, 146]. In Niger, farmer-managed natural regeneration of woody plants has contributed to some households' wood supply [147]. Although not yet very well developed in the region there is potential to use seeds from indigenous trees that have high concentrations of oil (as much as 65%) for production of energy. In some places this oil is used raw in running electrical generators, or in some areas processed into biodiesel.

Wood fuel production on farm can be an economically viable and sustainable option for smallholder farmers who struggle to satisfy subsistence needs and meet energy demand, while maximizing resource efficiency through allowing the reallocation of labour from wood fuel collection to agricultural production and off-farm income activities [118, 123, 148-150]. There is significant potential for further economic development of charcoal value chains when dryland residents and especially women become charcoal suppliers under enabling policy environments [113, 116]. In 2007, the charcoal industry in the region was already estimated to be worth over USD 8 billion, employing more than 7 million people in production and marketing or close to 1% of its population. By 2030, it is predicted that the market will exceed USD 12 billion, employing 12 million people [113]. Charcoal production offers dryland communities resilience as it increases during drought when other sources of income are unattainable.

Despite its economic significance, except in few African countries such as Northern Sudan where charcoal is sustainably produced under a favourable policy environment, in many SSA countries the charcoal market is generally viewed negatively and is often an informal and sometimes illegal business which reinforces unsustainable production. In Kenya and Namibia, it is legal but regulation is complex, multi-layered and corrupt. This generally results in low returns to farmers and higher prices to urban consumers because bribes amount to 10-20% of the final price of charcoal [151]. Streamlining and harmonization of policies is a prerequisite for an enabling environment for a sustainable wood fuel provision within agroforestry systems.

6.2.7 Gums and aromatic resins

Badal Hassan, Daniel Nyamai, Emiru Birhane and Mary Njenga

Gums and resins are important sources of income for the rural poor as well as a source of foreign exchange for countries in the drylands of East and West Africa and the Middle East [152]. They are hardened resinous plant exudates, obtained from several species of Acacia, Boswellia and Commiphora in the drylands. Currently, about 35 species of Acacia, Boswellia and Commiphora have been identified as potential producers of commercial gums and resins. But gums and resins are currently collected from only a few species [153]. Gum arabic is an exudate (oozed naturally or tapped by humans) from the stems or branches of *Acacia senegal* and *A. seyal* [154]. Frankincense is an aromatic resin oozed naturally or tapped by humans from various *Boswellia* species (*B. frereana*, *B. neglecta, B. papyrifera* and *B. secra*) while myrrh is a resin released by *Commiphora myrrha* and *C. holtziana* [155, 156].

The current global demand for gum arabic of approximately 100,000 MT (metric tonnes) surpasses the supply of 70,000 MT [157] with the majority of this coming from Sudan (60%). Smaller quantities are supplied by Kenya (potential of 3,000 MT against a production of 400-500 MT) and Ethiopia, which in 1984-1985 produced 4,200 MT, about three times the present level [158].

The global demand for aromatic resins is estimated at around 6,000 MT per year. In Eastern Africa the principal exporters of aromatic resins are Ethiopia (3,000 MT), Eritrea (400 MT), Kenya (1,500 MT) and Somalia (1,200 MT) [158-160]. In the period between 1998 and 2007 Ethiopia exported an average of 2,500 tons of natural gum and resin annually, and earned USD 34.1 million [153]. The largest markets are in China, Europe, Japan, Middle East, North Africa and USA, with emerging markets in Eastern Europe and South America. The exports of gum and resins from the region are considered very small relative to the resource potential [153].

Figure 6.2.7.1 left: *Commiphora malmal* tree tapped several times, **right:** tapped *Commiphora malmal* exuding myrrh. (Source: Badal A. Hassan)

Gum arabic production is based on cultivated and wild *Acacia senegal* and *Acacia seyal* trees while myrrh and frankincense are collected from wild plants. The collection of the produce starts with debarking of the tree upon which the exudates are collected and via natural ooze. The collected raw material is processed to avoid impurities and the products categorized based on size and colour. The processed gum is directly brought to the market and exported. There are possibilities for value addition because first grade quality gums and resins generate more income but inappropriate methods of tapping, collecting, processing, transporting, and storing result in a very small proportion of first grade quality, leading to marginal earnings. The management of the trees, particularly for frankincense production, is also far from sustainable as the debarking frequently damages or kills the trees [161]. The low level of tree management and focus on exporting bulk raw material underutilize the opportunities in the export markets.

Gums and resins are very important to the poor in the drylands of Eastern Africa because through exports they provide an opportunity to generate income in the dry season and during drought. They are mainly produced in the dry season when other economic activities are low thus offering a meaningful economic activity [162]. In addition to providing income, gums and resins are also used locally as medicines, in ritual ceremonies, as insecticides and hygienic and sanitation detergents. For example myrrh is used as medicine and to make traditional ink and burned to repel snakes and offensive insects. Frankincense is used for spiritual purposes by burning in mosques and churches, to fumigate houses and as a mosquito repellent. Moreover, the products are important ingredients for the perfume industry, pharmacology, medicine, food additives and chewing gum [163, 164].

Gender inequities and unequal power relations still exist and in some cases have led to unequal access and control over benefits from these natural resources. Myrrh is mainly harvested by men but also occasionally by widows to generate household income. Myrrh harvesting requires travelling long distances and staying in the forest for two to three weeks, which hinders the involvement of women in such activities. However, women and children of nomadic pastoralists are the main collectors of frankincense. Women and children also do manual sorting and cleaning to remove impurities including bark, soil and leaves, an activity which earns an individual USD 1.50 per day [165]. In Ethiopia more women than men are involved in local marketing of the products [166].

There are opportunities to generate greater social and economic benefits from sustainable use and exports of gums and resins. Appropriate policies and institutions are required to develop the markets and value chains to achieve these benefits. These may include (i) the development and implementation of non-destructive tapping and proper processing practices as well as internationally accepted standards and guidelines for quality enhancement, (ii) the development and implementation of a certification system to trace product origin and its sustainability and (iii) the promotion of value addition, for example, through extraction of essential oils by steam distillation or further processing of gum arabic into powder using appropriate mills. Lessons can be borrowed from some practices where gum and resin production has been formalized. For instance, gum/incense-producing companies contract individuals to harvest gum and resins in Ethiopia and destructive harvesting methods are prohibited [153]. Ways of engaging local communities in the management, production and benefits of the subsector should be seriously considered.

Promoting intensification of the use of trees to stimulate economic growth and exports bears a risk of unsustainability and inequity, and dedicated policies are required to avoid such undesirable side effects. Appropriate policies and institutions are thus critical to achieve sustainable and socially acceptable harvesting of gum and resin resources. Such policies and institutional reforms revolve around gender equity and community-based resource management as well as secure land tenure and tree ownership to facilitate equal access to and control over benefits from these resources. Equally important are the provision of incentives and empowerment of resource users to access markets, seize new financing opportunities like those in the regional and global markets for gums and resins.

Gums and resins are produced in the arid and hyper-arid drylands of Eastern Africa, with regional variation within these zones based on species endemism, knowledge and institutions. For instance, the best and most expensive frankincense is harvested from *Boswellia papyrifera*, *B. frereana* and *B. sacra*, species endemic to north Eastern Africa. *Commiphora myrhha,* the tree species producing real myrrh, is endemic and confined to the drylands triangle of Ethiopia, Kenya and Somalia. Technology and institutional capacity explain regional variation in market orientation of gum arabic. The biggest exporter of gum arabic, Sudan, has well developed institutions that support exports while Somalia, a potential exporter, lacks such enabling institutional environment because of 22 years of civil war.

6.3 Supporting services

6.3.1 Soil fertility management

Anthony A. Kimaro, Emiru Birhane, Jeremias Mowo, Ermias Betemariam, Mathew Mpanda and Kiros Meles Hadgu

Trees improve soil fertility through recycling of nutrients from the deep soil horizons to the topsoil layers and by fixating atmospheric nitrogen (N). The recycling of nutrients by trees takes place either through capture of nutrients from the deep soil horizons or interception of nutrient leaching beyond the crop rooting zone by tree roots. These nutrients are then released to the topsoil horizons through litter and root turnover. These processes play an important role in the recycling of nutrients in agroforestry systems [167] [167-169] and are critical for the ecological sustainability of improved fallow, woodlot and other agroforestry practices common in dryland areas.

The recycling of phosphorus (P) by trees is usually limited by high P-fixation in acid soil, low mobility in the soil, and low foliar P concentration [168]. Consequently, external P input is necessary to sustain crop yield on P-deficient soils because the amount recycled by short-rotation fallows of 1-3 years is often lower than amounts extracted via crop harvest [170]. However, in areas with sub-soil P reserves, trees raise topsoil N and P to levels sufficient for maize production [171, 172]. Trees also accumulate other nutrients from the soil and may alleviate nutrient deficiencies, especially potassium (K) that can arise when sufficient levels of N and P are supplied [148].

Agroforestry transfers nitrogen from N-fixing trees to nearby crops. The transfer takes on the surface and below-ground through decomposition of pruning or litter, root and nodule turnover, roots exudates via mycorrhizal connections and via the buildup of soil organic matter [168, 170]. The amount of N fixed varies widely among species but for fast growing tree species like *Sesbania sesban* (L.) Merrill., *Cajanuscajan* L. Mill sp., *Gliricidia sepium* (Jaqua) and *Tephrosia vogelii* Hook. f., fixation can accumulate about 100–200 kg of N per hectare per year [148]. These amounts are substantial and can replenish soil N to levels sufficient to grow up to three subsequent maize crops on N-deficient sites [171].

Trees also improve soil structure, and fertility through the buildup of soil organic matter (SOM). Trees add SOM by fixing carbon during photosynthesis and subsequent transfer to the soil through litter fall and root turnover. These plant materials are then converted to SOM by soil microbes through decomposition and humification processes. Besides, nutrient supply, the decomposition of SOM may increase plant-available nutrients in the soil through the reduction of P-sorption capacity of soil and supplying energy sources to soil micro-organisms responsible for nutrient cycling [173]. It is natural to find higher populations of micro-organisms in soils under agroforestry compared to treeless land use [173, 174]. Besides improving soil quality, micro-organisms, such as mycorrhizal fungi, enable terrestrial plants to effectively access nutrients and water under stress conditions by forming association with plants that can alleviate the stress symptoms [175]. Thus, trees drive nutrient cycling and transformation in an ecosystem through their influence on SOM, soil micro-organisms and chemical processes in the soil.

Management of fertilizer trees by farmers

The Faidherbia-maize system in Tanzania and the Faidherbia-teff system in Ethiopia are traditional agroforestry practices in which *Faidherbia albida* is retained and managed by farmers for soil fertility improvement and provision of other ecosystem services such as dry-season fodder for livestock. Other dryland agroforestry practices in Eastern Africa for soil fertility management include improved fallow and rotational woodlots in Tanzania [126, 172] and in Kenya [123].

Fallows of fertilizer trees can improve soil fertility at levels sufficient to reduce inputs of N and P fertilizers by 50% [176]. In semi-arid zones, crops yield improvements by tree/shrubs fallows can partly be associated with alleviated soil moisture competition due to sequential cropping [176]. Moreover, deeper rooting and slower initial growth of perennials relative to most cereal crops [171] may reduce competition through differentiation of root niche and peak resource demand; hence facilitating coexistence of perennials and annuals in mixture even in the drier areas in Eastern and Southern Africa [176, 177].

Figure 6.3.1.1 Left: *Faidherbia albida* retained on-farm and maintained by farmers to enhance fertility in maize-based systems in Tanzania and **Right:** teff-based systems in Ethiopia Photos: left M. Mpanda, right E. Birhane.

Contributions to agro ecosystem resilience

Agricultural practices in semi-arid and arid zones in Sub-Saharan Africa are characterized by extensive rather than intensive farming practices as a strategy to increase crop production. For Eastern Africa, this approach gives typically low yields of maize at 1-1.2 tons per hectare despite increasing the area under cultivation by about 8 million ha since the late 1960s. This trend of agricultural expansion (without adapting the methods to low-rainfall/higher temperature conditions) in Eastern Africa is unsustainable and is associated with deforestation and land degradation. However, fertilizer trees can rehabilitate degraded farmlands, and increase the resilience of dryland farming systems [121, 178].

Increased resilience of dryland farming systems with trees is attributed to a number of factors, including the moderating effects micro-climatic of trees on crops [178-180] and higher structural and functional diversity relative to monoculture systems [124].

These factors help to sustain and diversify production cycles in agroforestry systems and hence, minimize risk due to climate variability in the semi-arid and arid zones. For instance, improved soil moisture retention in soils under *Sesbania sesban* fallows in Malawi and *Acacia* spp. in woodlots in Tanzania compared to maize fields and *F. albida* canopy in the Ethiopian parklands relative to the open area [126, 181]. The shading effects by trees on-farm increase millet production in dryland agro-ecosystems in the Sahel [178]. Research also indicates that maize yield fluctuations resulting from climate rainfall and temperature variability can be mitigated by strategically combining legume trees and supplemental fertilization to increase rainwater use efficiency [121].

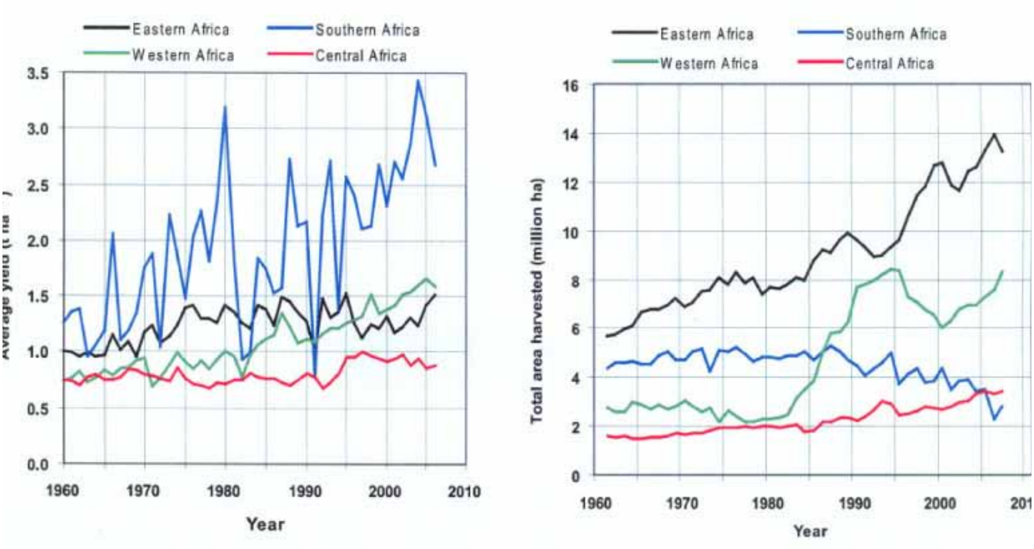


Figure 6.3.1.2 Trends in average grain yield and area of maize harvested in different regions of Africa, with average annual yields for 1961–2007 in each region obtained from FAO (2008). **Source**: [182]. ICRAF Policy Brief No. 02.

Towards broader adoption of fertilizer tree systems

Several African governments have taken initiatives to develop national programs towards complementing the use of artificial fertilizer by increasing trees on-farm for tree products and other ecosystem services. These programs include the 10% cover target in agricultural landscapes in Kenya, the climate resilient green economy (CRGE) in Ethiopia that aims to plant 100 million *Faidherbia* trees for rehabilitating degraded farmlands and improving soil fertility and crop production. The goal of the Ethiopia initiative is to increase economic growth while reducing greenhouse gas emissions and increasing climate resilience. *Kilimo Kwanza* (Agriculture First) is an initiative, which aims to transform the Tanzanian agricultural sector into a modern "Green Revolution" style commercial sector.

6.3.2 Soil moisture

Julia Wilson and James Ndufa

While trees generally positively influence overall productivity of dryland ecosystems, they also directly affect the growth of crops and grasses in their vicinity, through effects on soil nutrients, above-ground micro-climate and soil moisture [183]. In this section we focus on the role of trees in accessing and using water and the concomitant effects on production of neighbouring crops and grasses, and indicate prospects for manipulating the relationships between trees and crops.

Opportunities exist to increase the overall primary production of dryland ecosystems through management of the water balance, because in arid and semi-arid areas only 5–30 % of rainfall is used in plant production [184, 185]. Options to increase the green water use efficiency (GWUE, the proportion of rainfall used for transpiration) include rainwater harvesting techniques that promote infiltration and mulching to reduce evaporation from the soil surface as well as the inclusion of trees. Trees may increase GWUE by (i) capturing and redistributing water which has percolated below the crop rooting zone, (ii) using soil moisture for conversion to tree biomass when crops or grasses are not actively growing and (iii) improving infiltration rates and soil water-holding capacity.

Figure 6.3.2.1 The spatial distribution of tree and crop root systems, showing overlap in the surface soil layers.

The combination of deep-rooted perennial trees with shallow rooted short-lived crops and grasses provides opportunities for *complementarity* and *facilitation* but also risk of *competition* between trees and shallow rooted species. Crop and grass roots are mostly in the top 0-80 cm soil horizon where soil moisture is highly variable, due to evaporation and rainfall. Tree seedlings root in the same horizon and are correspondingly vulnerable to drought, but rapidly develop taproots reaching deeper soil horizons with more stable moisture supply. A mature tree has a combination of lateral roots in surface zones, extending well beyond the tree canopy edge, and overlapping with the crop rooting zone (Figure. 6.3.2.1), and deep roots reaching up to 20–30 m below ground which may access ground-water [186]. The overlap of tree and crop root systems leads to competition for moisture (Figures. 6.3.2.2-4) when tree and crop roots are active in the same zone and the same season, but there may also be both spatial and temporal complementarity in resource capture, and facilitation. The overall productivity of the system thus is a reflection of the balance of these processes.

Spatial complementarity in soil moisture capture arises (a) through the differences in rooting architecture of trees and annual crops, which enable trees to access deeper water resources than crops, or (b) when trees and crops are grown separately, as in woodlots. *Temporal complementarity* occurs when trees use soil moisture outside the growing season of the crops, when 20–30% of annual rainfall may occur [187], or when trees are grown as part of rotational fallows. Evergreen trees and *Faidherbia albida* (which has reverse phenology, i.e. it possesses leaves in the dry season and loses them in the rainy season) are the most outstanding examples of tree species which use off-season rain, but so do many deciduous species to varying extents.

Facilitation occurs when shallow rooted species take up and benefit from water released by trees. At night, many tree species including *Vitellaria paradoxa* and *Parkia bi-*

globosa of the West African savannah [188], release moisture taken up from wetter soil layers into drier upper soil horizons, a process known as hydraulic redistribution. In dry systems at the peak of the dry season the released water may comprise 17–81 % of tree transpiration the following day [188, 189]. However evidence of its significance for crop growth is limited as much of the redistributed water may be re-absorbed by the tree.

The relationship between trees and crops also pose some challenges that need to be addressed. For instance, competition for soil moisture occurs when tree and crop roots are actively taking up water from the same rooting zone. This may happen during the entire year but is particularly detrimental at the start of the rainy season when woody species with their perennial roots are at a competitive advantage to use soil moisture over annual species, which may struggle to establish as a result of this. Periods of competition may alternate with complementarity and facilitation.

Figure 6.3.2.2 Reduced maize growth close to Leucaena collinsii trees at Machakos, Kenya.

An ICRAF field study at Machakos, Kenya highlighted a range of competitive effects of trees on crops. Plots with eight linearly planted tree species were intercropped with maize and beans and corresponding crop-only plots were monitored for several years. Competition with crops became evident when trees were 2.5 years old and differed between tree species, it increased as trees aged and was affected by seasonal rainfall (Figures. 6.3.2.2-4). Trees reduced soil water throughout the profile to the maximum depth of 1.8m and zones closest to trees were most depleted (Figure. 6.3.2.4). The highest tree and crop root densities coincided in the upper soil layers [190] and sapflow studies [191] showed that while trees extracted water from moister deep soil layers in the dry season, they rapidly switched their water uptake to the surface layers at the onset of the wet season, rendering competition with crops inevitable. Farmers recognize that trees have both positive and negative effects on crops, but their perception may not always be correct. For example, on-farm studies in Kitui Kenya (where crop failures are frequent due to drought) of the effects of the tree *Melia volkensii* on crops revealed that 10 trees ha^{-1} would reduce maize yields by 219 kg ha^{-1} (*c.*20 % of potential yield), however only 5 out of 20 farmers surveyed thought that *Melia* competed, while 8 out of 20 thought that it did not [192].

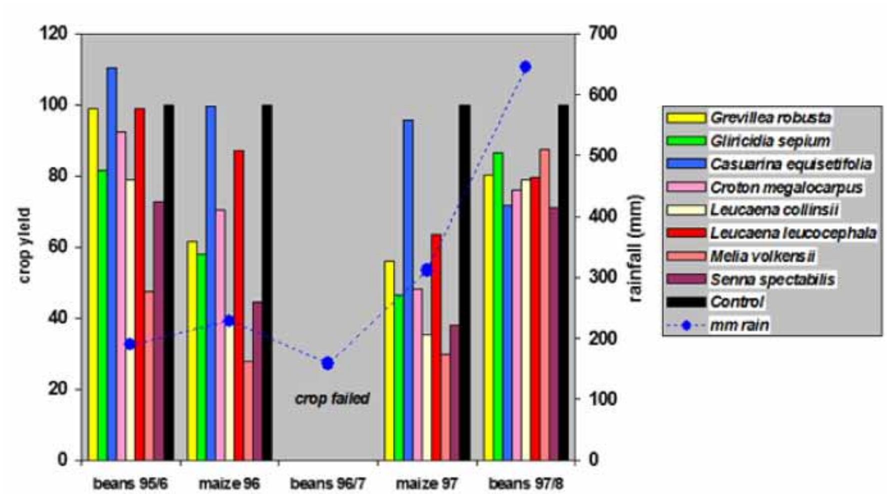
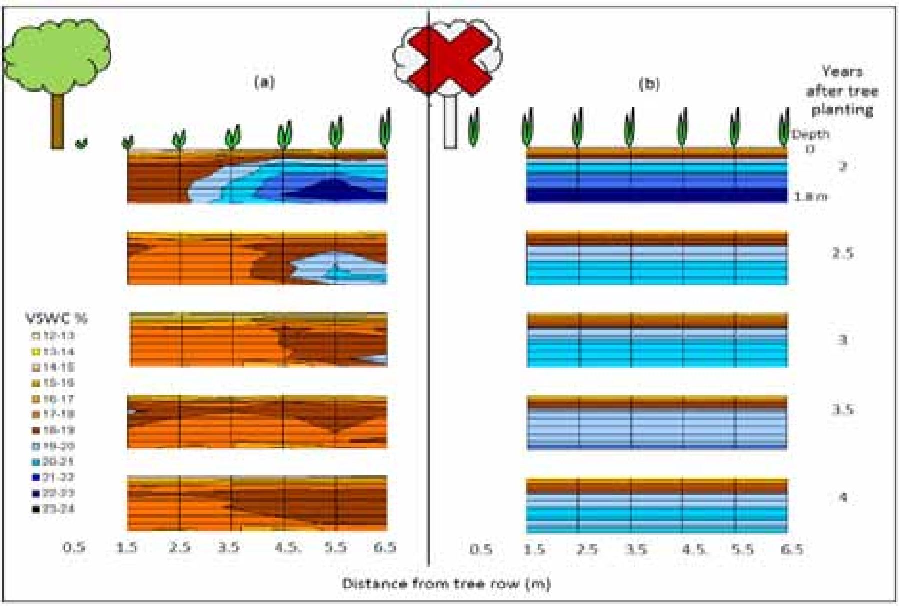


Figure 6.3.2.3 Effects of trees on soil water in an agroforestry system at Machakos, Kenya: volumetric soil water content (VSWC) at various depths and distances from trees 2–4 years after tree planting; (a) with, and (b) without Gliricidia sepium trees



Source: [193].

Figure 6.3.2.4 Agroforestry study at Machakos, Kenya: comparison of intercrop yields over 5 successive growing seasons when grown in conjunction with 8 different tree species as % of yield in crop only control plots.

Trees were 2.5–4.5 years old, with variable rainfall. Trees planted in 1993, intercrop yields declined as trees grew and low and erratic rainfall in 96/7 season resulted in complete crop failure. High rainfall in 97/8 restored intercrop yields to 80 % of those of crop only control plots.

There are many options to control competition [194] [194, 195], including selection of less competitive species, temporal separation of trees and crops using rotational fallows, spatial separation by root barriers or using woodlots and use of tree management practices including crown and root pruning to separate zones of water uptake. Pruning of tree crowns reduces transpiration demand and pruning of shallow tree roots forces extraction of soil water to deeper layers. Farmers can learn how to control competition and at the same time obtain useful tree products before trees have reached maturity [194, 196-200].

Short-lived crops can fail for many reasons, and drought or erratic rains at any stage from germination to crop maturity can significantly reduce yields, or lead to crop failure. Trees are more robust and unlikely to die unless there are repeated long-lasting droughts. Thus, while trees may themselves reduce crop yields, their products can and do provide farmers with vital resources and a more resilient cropping system. Bear in mind that potential benefits need to be weighed against the issues of tree competition. Tree pruning allows farmers to manipulate the trade-offs between the annual and tree-crops, while also obtaining additional animal fodder or other useful biomass.

The access by trees to water resources not available to crops and the grasses and herbs that support livestock, enable trees to increase the overall primary productivity of semi-arid lands and increase the GWUE, it also allows trees to provide valuable products, providing resilience during the lean times of dry season and drought. This constitutes supporting ecosystem service, which supports the delivery of provisioning, regulating and cultural ecosystem services.

6.3.3 Biodiversity and ecosystem services

Mary Njenga, Jan de Leeuw, Catherine Muthuri, Miyuki Iiyama, Ramni Jamnadass

Biodiversity in Eastern Africa drylands

Biodiversity is the degree of variation of life forms within a given species, an ecosystem, a biome or the planet. Human societies depend on the supporting services offered by biodiversity because they underpin the supply of provisioning, regulating, cultural and other services. Or as phrased in the Millennium Ecosystem Assessment [201], "it's the diversity of biota across the world that underpins the capacity of the world's ecosystem in providing most of its goods and services."

Drylands are endowed with a rich biodiversity including charismatic wildlife species such as the lion (*Panthera leo*), African elephant (*Loxodonta africana*), leopard (*Panthera pardus*) and buffalo (*Syncerus caffer*). While these species attract millions of tourists annually, it is commonly overlooked that drylands host a vast number of trees and shrub species such as acacia and baobab and many of the world's grasses. Overall, 10,000 mammals, birds and amphibian species occur in the world's drylands and the drylands of SSA provide a habitat for 60% of mammal, bird and amphibian species found in that region [202].

Generally, dry tropical forests are smaller in stature and less complex floristically and structurally compared to wet tropical forests [203]. On the scale of several hectares or less, dry forests average about half or less the number of tree species of wet forests and the number of species increases along a moisture gradient with lower tree species richness found in the driest areas. Reflecting the overall smaller stature of dry forest is a relatively lower biomass than wet forest and a net primary productivity (NPP) averaging 56-75% of that of wet forests [203]. Further, dryland species richness decreases with aridity, which is associated with decreasing primary productivity [204, 205]. Because of the shorter growing period, annual diameter growth in dry forest trees is also about half that of wet forest trees. However, because of the relative simplicity and small structure of many mature dry forests, dry forests have the potential to recover to a mature state more quickly than wet forests, and may therefore, be considered more resilient [203].

To what extent does tree species diversity underpin the delivery of provisioning, cultural, supporting and regulating services by trees?

A survey was carried out among participants of the consultative process (see chapter 2) to assess their appreciation of the importance of tree species diversity in supporting the various ecosystem services. Figure 6.3.3.1 reveals that respondents ranked the importance of the contribution by trees with a score of 3.0 on average across all ecosystem services, which corresponds to a high importance. Provisioning and cultural services received a somewhat higher average score than the regulating and support services probably because of the tangible goods derived from these services and their direct contribution to human well-being. The difference is slight however, and the score of 2.9 for regulating and supporting services indicates that the experts participating in the survey appreciated the importance of trees to underpin these two ecosystem services.

There are a number of reasons why tree species diversity is important for the delivery of ecosystem services. First, a diverse assemblage of tree species is likely to provide a greater variety of ecosystem services than a monoculture. A diverse tree species assemblage is attractive to rural people, because it is convenient to have species within walking distance providing not only shade, food and forage, and medicine, but also fuelwood and products that can be marketed in combination with species which regulate the environment and enhance primary production. This on-site diversity is particularly beneficial when tree species differ in the services that they provide, or in other words, species offering complementary ecosystems services. There is complementarity for example when one tree which provides fruits and medicine and poor quality construction and fuelwood neighbours a species that excels in this respect. There is also temporal complementarity, for example while tree species provide food for a shorter period, an assemblage of tree species might offer a more continuous provisioning of food throughout the year. High on-site species diversity is common in multifunctional agroforestry landscapes. Second, landscapes are heterogeneous in terms of the biophysical factors that affect the growth of plants, for example variation in groundwater depth, soil catenas and intensity of use of land and of trees, and tree species assemblages generally vary in space as a result of this. This landscape diversity is beneficial to people particularly when it offers a greater variety of species and ecosystem service benefits than a homogenous environment.

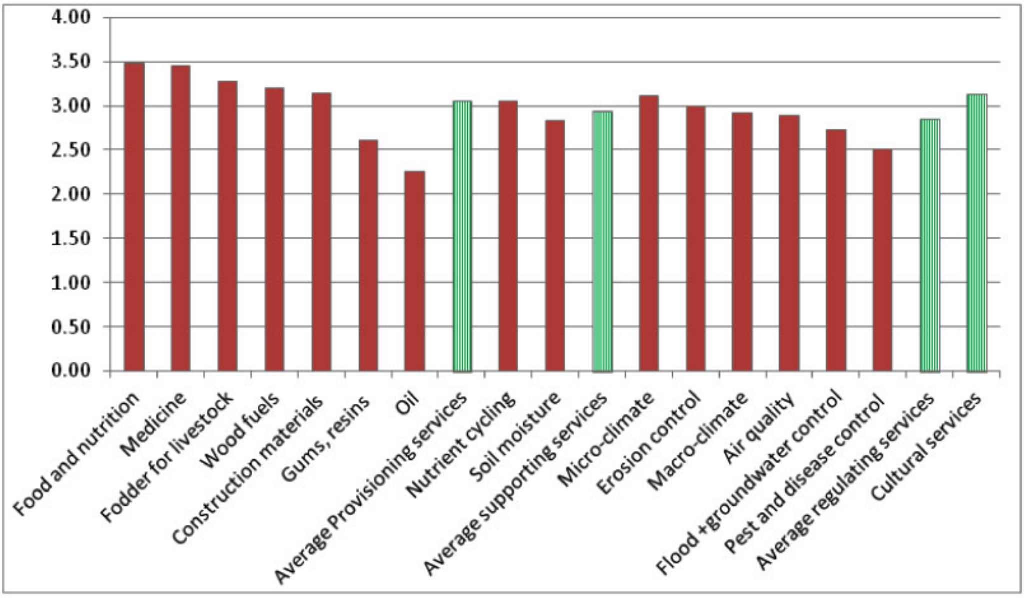


Figure 6.3.3.1 Statistics describing expert opinions (n= 36) of the importance of tree species diversity in supporting a number of ecosystem services. 4 Very high, 3 High, 2 Moderate, 1 Low, 0 Not important

People manage this diversity in intensively managed landscapes, where they selectively promote or discourage native species and plant trees to enrich the pallete of ecosystem services. Yet rural people frequently consider trees from a multipurpose perspective. Fruit trees are planted near the house to provide fruits but also to offer shade, which is a highly appreciated service. In addition, besides species diversity, other factors like the spatial arrangement and size of trees has a significant effect on regulating and supporting services. For example, size and spatial arrangement of trees in farms and landscape units over large areas influence the micro-climate particularly the temperature and soil moisture.

Genetic diversity was not covered in the above ranking. Observations from experimental translocation of germplasm from various origins reveals that there is significant genotypic variation among many African dryland tree species. Thus far there has been very little germplasm selection among these species. Wild varieties may further be a 'biogenetic resource' for cross-breeding and improvement of domesticated species to which they are genetically related [206].

Overexploitation and diversity
Some products such as fruits for human consumption, fodder for livestock and medicine are limited to certain trees species and over-exploitation of those species in the wild and on farm has turned out to be a major threat to biodiversity. Similarly charcoal producers select certain hardwood species in drylands resulting in a decline in tree species diversity. "To ensure conservation of natural stands and maintain tree species diversity, there is need to plant them on farm in agroforestry systems" [207]. Besides that, it is important to explore the quality of charcoal produced from other less preferred species. Harvesting of trees for various products or harvesting products from trees should be carried out in a sustainable way, for example, by using non-destructive methods in harvesting gums and resins, fruits and leaves (see sub-chapters on gums and resins, trees for food) which will contribute to conservation of tree species both in the wild and in agroforestry systems. Species diversification in tree domestication is important as some trees are better for certain uses than others. For example, some provide quality timber while others are used for medicine, gum and resins or fixing atmospheric nitrogen. It is important to note, as mentioned earlier, that trees are predominantly multipurpose in nature as they may clean the air by taking up carbon dioxide and collecting dust, regulate water hence improving soil moisture, provide shade hence reducing soil temperatures and/or provide fruits, leaves for both human and livestock consumption. Equally important is valuing diversity on intra utility (having different species for similar utility) as well as diversity on inter utility (having different species for different utility).

High tree species diversity diversifies livelihood opportunities and builds resilience of communities in Eastern Africa drylands, for example, by gathering fruits and leaves for both home use and sale during drought when crops fail and livestock die. Livestock also benefit a lot from browse material when grass dries up during the dry season.

6.4 Regulating services

6.4.1 Trees and micro-climate

Catherine Muthuri, Jules Bayala, Miyuki Iiyama and Chin Ong

In the African drylands trees/shrubs are often mixed with annual crops in the rangelands and the farmed fields. Combining woody and non-woody plants in mixtures modifies microclimatic factors such as wind speed, air and tissue temperatures, relative humidity and radiation, saturation deficit of under-storey crops and consequently affecting evaporation [208-210]. Therefore, compared to an open environment, the modified micro-climate under trees has reduced solar radiation, a more moderate temperature regime, higher humidity, lower rates of evapo-transpiration and higher soil moisture levels [211], affecting both crop growth and livestock performance.

Table 6.4.1.1 summarizes the relative effect of tree crown under and away from the crown [212]. Soil temperature, wind speed, light intensity and soil evaporation are relatively lower under the crown than in the open while the other two parameters are higher.

Table 6.4.1.1 Comparison of the effects of micro-climate under tree crowns and in open areas, in agroforestry systems with dispersed trees on cropland [212]

Parameter	Relative effect
Soil temperature	under crown < open area
Wind speed	under crown < open area
Relative humidity	under crown > open area
Light intensity	under crown < open area
Soil evaporation	under crown < open area
Water infiltration	under crown > open area

Micro-climate modification by trees affects crop growth in various ways. In agricultural systems of African dryland conditions, crops often use a small fraction of the rainfall input due to unproductive loss of water principally via soil evaporation, runoff and drainage [213, 214]. Tree shade can significantly reduce supra-optimal temperature, radiation, soil evaporation of the near surface atmosphere leading to higher soil moisture (HR) with a major impact on crop performance [185, 213, 215, 216]. In general, shade will create micro-climates with lower seasonal means in ambient temperature and solar radiation as well as smaller fluctuations [217]. For example, in Niger *F. albida* shade-induced reduction of soil temperatures (at 2-cm depth the reduction was by 5°C to 10°C depending on the movement of shade) particularly at the time of crop establishment, contributed to the better growth of crops under these trees [218]. Trees can also lower mechanical impact of wind/rain speeds to minimize damage on newly established crops [213, 219]. In coffee and cacao plantations shade trees have been observed to buffer high and low temperature extremes by as much as 5°C. [220]. The figure below shows weekly mean soil temperature at 5-cm depth, measured at Saponé, Burkina Faso, from under large and small trees of néré (*Parkia biglobosa*) and small trees of karité (*Vitellaria paradoxa*), and in the open field [221]. It is clear that temperatures in the open field are generally higher than under the canopy with the lowest temperatures being under the large néré canopy. The results showed that the combined beneficial effects of temperature modifications and soil fertility could exceed the negative effect of tree shade. In contrast, in Mali, [222] concluded that lower sorghum under the two tree species were due to changes in micro-climate, which increased the incidence of fungal diseases of crop seedlings. Thus, micro-climate changes can be beneficial or harmful depending on the season.

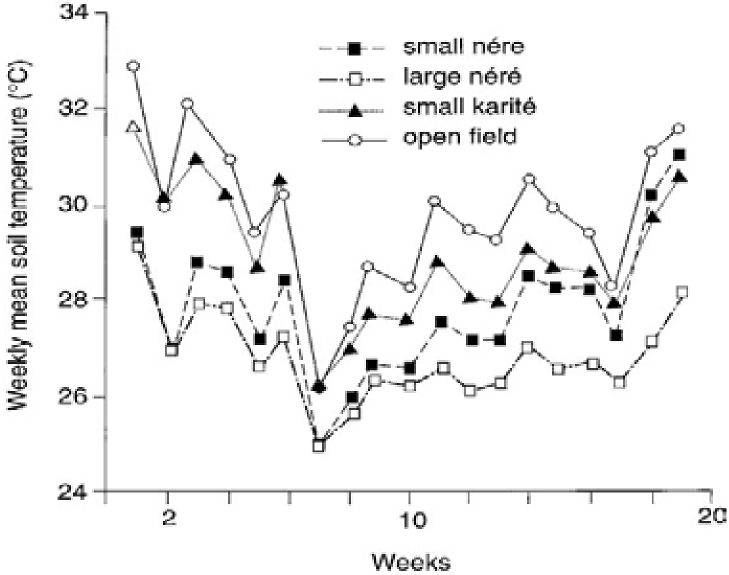


Figure 6.4.1.1 Weekly mean soil temperature at 5-cm depth, measured at Saponé, Burkina Faso, from 29 June to 15 November 1994 under large and small trees of néré (*Parkia biglobosa*) and small trees of karité (*Vitellaria paradoxa*), and in the open field. Tree crown diameters ranged from an average of 8.6m to 13.1m. *Source:* [221].

Micro-climate modification by trees also provides ecosystem services that benefit live-stock. In the rangelands of Eastern Africa, grass productivity was reported to be higher under trees due to the lengthening of the phenology of the grasses due the combined effects of shade and water availability [210, 223, 224]. Moderation of pasture micro-climate provided by trees further protect livestock from heat stress, wind, chills and severe weather events [225] Consequently, the use of agroforestry systems is an eco-nomically feasible way to protect crop plants from extremes in micro-climate and soil moisture and is a climate-smart adaptive strategy for farmers [226].

Management aspects

Farmers in arid and semi-arid rain-fed conditions in Africa are resource-constrained and cannot afford capital-intensive technological solutions such as irrigation. In drylands farmers often opt to deliberately manage trees on farm, if not actively planting trees, to benefit from moderating micro-climate as well as to procure food, fodder, timber and wood fuel [213, 227]. Indeed farmers may deliberately plant fast-growing, competitive tree species if they provide attractive economic returns or carbon credit subsidies [214].

Examples where the beneficial aspects of microclimatic changes are extensively used are shade trees to protect heat-sensitive crops, wind breaks and shelter belts to slow down the wind speed to reduce evaporation and physical damage to crops, and various crop-tree mixes to reduce erosion and maximize resource use efficiency [217]. Recent ICRAF research in a semi-arid central Ethiopia (ACIAR preliminary finding) revealed that farmers ranked shade, after wood fuel, the second most important reason to maintain and manage trees on farm (Iiyama et al. unpublished).

Figure 6.4.1.2 Left: Cattle under *Faidherbia albida* shade in Southern Zambia and **Right:** Livestock kraal under the shade of a tree canopy in semi-arid zones in East Shewa, Oromia, Central Ethiopia.

The role of traditional knowledge and indigenous technology in the climate-stabilizing effect of trees is substantial. These are location-specific often age-old practices that are efficient in preserving the resource base without much degradation and are effective in making the best use of scarce agro-climatic resources in a sustainable manner [225]. Women's knowledge, which is often under-valued, is of critical importance to protect and manage trees on farm for micro-climate benefits. For example, a study examining farmers' knowledge and management of agroforestry parklands in a Sudano-Sahelian region of Mali indicates that many women identified shade, cooling, and ''less heat'' as important environmental benefits of parkland trees whereas no male study participant identified lower temperature as a micro-climate effect. At the same time women reported having been implicitly or explicitly excluded from major household decisions in parkland agroforestry [228].

Sustainability

There is evidence that tree population is decreasing and that is partly related to climate change whereas human pressure constitutes another cause [229, 230]. However, there is hope with evidence of tree density increasing on farmed lands (Zomer et al. 2009). If human pressure is transforming more and more dry savanna into farm lands and at the same time tree population increases in farmed lands, the micro-climate-moderating services trees provide will improve.

Regional variation

Although agroforestry provides a broad range of ecosystem services and environmental benefits[231], these vary by ecological region and according to tree management practices.

Micro-climate influences varies from one agro-ecological zone and season to another where for instance the ameliorative influence of tree shade on understorey micro-climate was reported to be greater in low (<800 mm) compared to high rainfall zones [216, 232]. On the other hand, the net shade effect was reported to be more positive when the annual crop is a C3 plant like beans which is normally light saturated in the open than when it is an understorey crop like maize [233].

Since the microclimatic modifications within agroforestry systems depend on tree/crop combinations, tree spacing and height, and the prevailing climatic conditions, the benefits or otherwise of agroforestry are strongly dependent on the specific technology adopted [210]. In addition, the tree row orientation and distance influence the growth behaviour of the crop but the effect of sun angle (which changes with season) can change their influence over time [234]. The potential benefits of micro-climatic amelioration are often negated by decreases in soilwater supplies caused by interception losses from the tree canopy and depletion of available soil moisture.

Attempts to reproduce these benefits by introducing agroforestry in similar environments have often been disappointing [213]. Because soil, climate, trees/crops/animals are location specific, practices developed in one region may not be ideally suited to soil fauna and flora of a different region [235]. Detailed information regarding conflicting interactions is vital to design systems which maximize microclimatic benefits.

6.4.2 Air quality and human health

Erick Otieno Wanjira, Jan de Leeuw and Mary Njenga

Dust exposure is thus far little recognized as a threat to the health of people in the drylands of Eastern Africa. Trees planted in the areas of origin of the dust and around human settlements have the potential to reduce exposure to dust, and therefore health gains are possibly achievable through trees. Policies promoting such health gains are currently absent, and this section argues what would need to be done to convince policy makers on the need to invest in trees to improve human health in the drylands of Eastern Africa. Dust also stresses livestock, upon which the nutrition and livelihoods of populations in Eastern Africa's drylands largely depend hence affecting their health.

Exposure to dust is a threat to human health because, when dust is inhaled, it causes a range of respiratory diseases, including asthma, chronic obstructive pulmonary disease and pneumonia [236]. Dust also impairs visibility for both humans and livestock and is a transportation safety concern. Surprisingly, little attention has been paid to the health effects of dust exposure in Africa.

Figure 6.4.2.1 Dust caused by swirling winds – a common sight in African drylands.

A recent paper by De Longuevile et al[237] identified this remarkable lack of interest in the health impacts of dust exposure in West Africa. The neglect of this important matter is surprising for two main reasons. First, African drylands, which contribute over 50% of total global atmospheric dust circulation, have dust concentrations [238] systematically higher than any other region of the world. Second, high child mortality associated with respiratory illnesses in developing countries, especially in Africa, has been partly attributed to exposure to dust [239, 240].

Although little is known about exposure to dust in Eastern Africa drylands, it can be assumed that there are regional variations, due to the significant variations in wind speeds in the region. High wind speeds prevail in the coastal parts of Somalia and Djibouti as well as the Lake Turkana area of Kenya. These are dryland areas with significant areas of bare soil and thus are likely to have high dust loads.

Lack of vegetation cover is a major factor increasing the atmospheric dust loads. This contributes to explaining why barren lands in desert areas are a major source of dust. Dust is also generated in moister drylands when overgrazing and land degradation expose soils which otherwise would have been protected by vegetation. Both grasses and trees reduce wind erosion and help prevent the loading of dust into the atmosphere. In addition, trees have the potential to reduce the load of an already dust-laden airstream by lowering wind velocity to below the threshold at which particles remain airborne. Having trees around human settlements thus reduces dust exposure and could have a positive impact on human health.

To date these potentially positive effects of trees on the health of African dryland residents have received limited attention. Compelling arguments would be required to convince decision-makers that there is a need to develop policies to foster the planting and regeneration of trees in drylands to improve human and even livestock health. Currently, it would be difficult to develop such convincing arguments because the underlying information and evidence base is limited. We need insights into and data regarding the negative impacts of dust exposure on human health in the drylands of Eastern

Africa, the health gain that could be achieved through the establishment of trees in areas of origin of the dust and the areas of exposure and the economics of investing in this. Good data already exist on the positive health effects of trees/plants on *indoor* air-quality. The challenge before us is to carry over the concept to the greater (dryland African) outdoors.

6.4.3 The water regulation service of dryland agroforestry ecosystems

Uriel Safriel

Trees and the water cycle

Trees constitute a structural component of biodiversity of much significance in driving the water cycle at local, watershed and global scales. Through this they underpin the water regulation service of terrestrial ecosystems, agroforestry systems included. Non-tree plants, that jointly with trees constitute the vegetation covering our planet's lands are similarly instrumental. However, quantitatively and sometimes qualitatively, the effect of trees on the water cycle, and hence their contribution to the water regulation service is much stronger than that of non-tree plants (Figure 6.4.3.1).

There are many differences between trees and non-tree plants. Traits differentiating trees from non-tree plants in water cycle functionality include their physical dimensions expressed in greater height and volume of foliage and canopy, and in the below-ground depth and volume of their root system. Furthermore, their perennial life cycle and high morphological resistance to physical pressure confer resilience to the water regulation service. In addition, while non-tree plants occur in all terrestrial ecosystems, tree abundance, density, species richness and diversity, decline towards the climatic extremes of the planet and trees are rare or absent in polar, alpine and the desert areas. However, almost all cultivated lands occur in areas with climate favorable to trees and their diversity, density and spatial distribution is determined here by management rather than climate. This is often the case of agroforestry systems, where the land user who manages the tree species composition and abundance determines the degree to which trees underpin the water regulation service of the system. In this section we will address the water regulation services of trees, even though other plants, including crops, contribute but usually with much smaller effect.

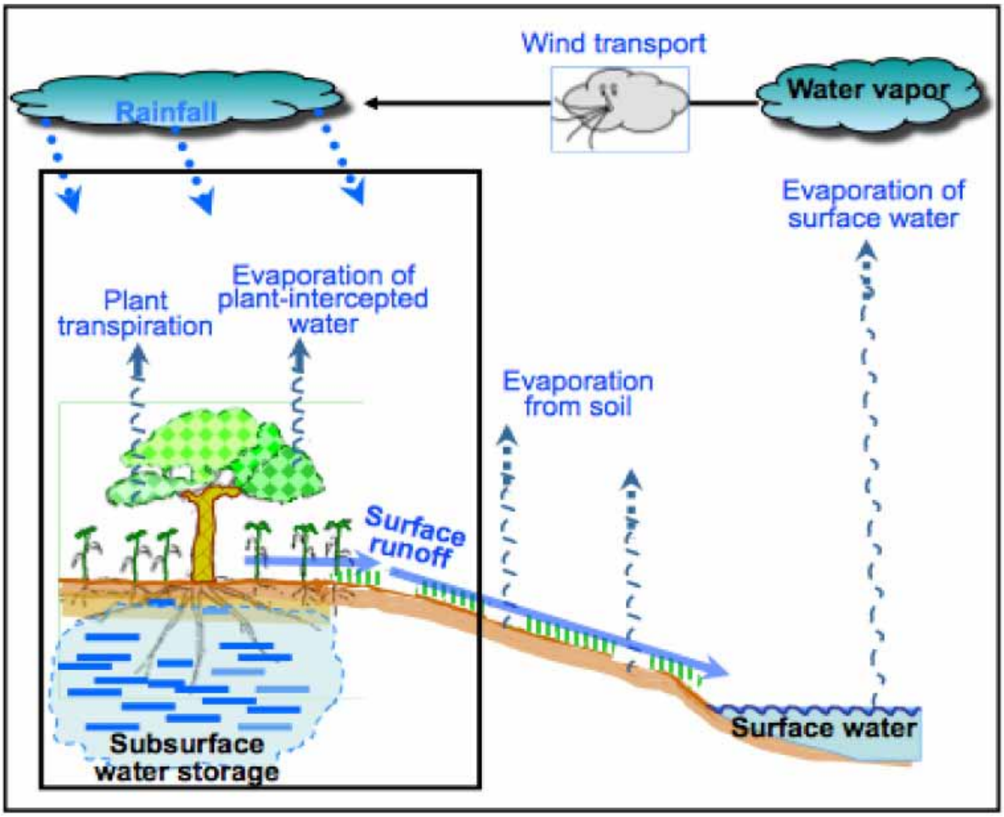


Figure 6.4.3.1 - The water cycle – bolded script stand for storages, and blue script and arrows stand for processes. Inset: the role of trees.

The partitioning of rainwater

The start of the water cycle is the water vapor in clouds transporting water evaporated from large water bodies to land areas to be discharged as precipitation. Gravity moves a fraction of this precipitation laterally as *surface run-off* that may flow into rivers, lakes and oceans. Another fraction flows mostly vertically into the soil to *storages* – the soil moisture storage and the groundwater storage components. A third fraction, that of the *evapotranspiration*, returns the rainfall counter gravity as vapor back to the atmosphere, either through *evaporation* directly from the soil surface and from tree surfaces (leaves, branches and trunks) or through *transpiration* - a live pump consisting of the tree vascular system that transports soil moisture (and in case of many trees also groundwater) to the surface of leaves where the water vaporizes and is returned to the atmosphere. Terrestrial vegetation regulates global to local water cycles while partitioning rainfall over these three fractions of the water cycle and this effect of vegetation comprises the water regulation service of terrestrial ecosystems (Figure 6.4.3.2).

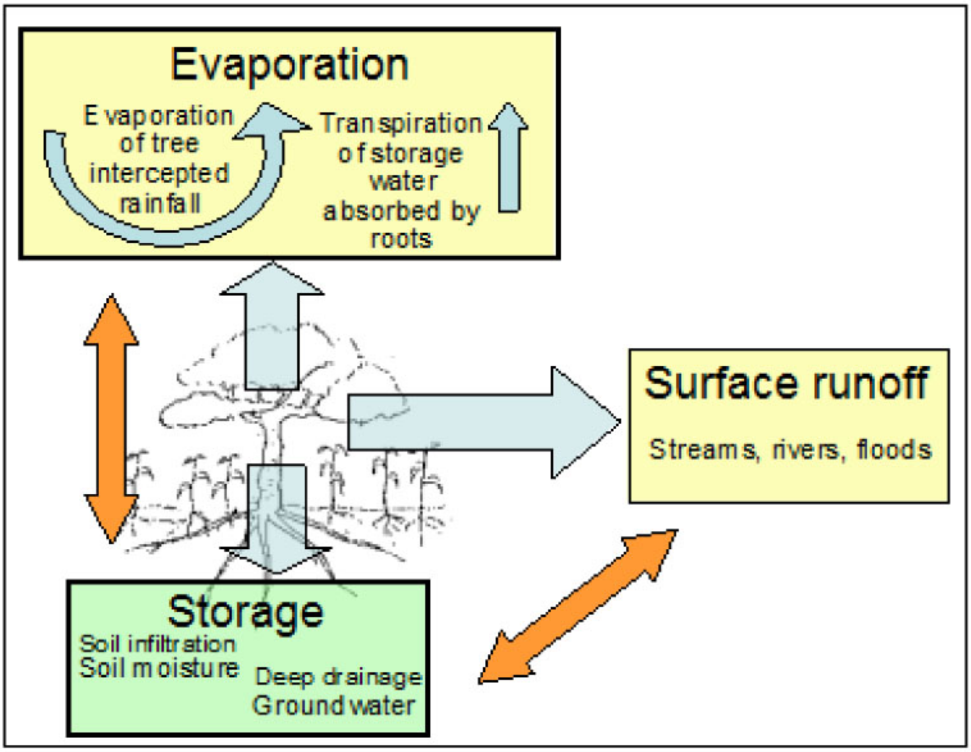


Figure 6.4.3.2 – The water regulation service in which trees are involved – regulating the size of the three fractions of rainfall – vertical upwards (evaporation), lateral (surface runoff), and vertical downward (storage). The orange-colored double arrows stand for the major tradeoffs of tree functions in the water regulation service.

Since biological productivity in drylands is limited by water, the land-user of a dryland agroforestry ecosystem would expect the tree component of the system to regulate the water cycle such that it minimizes evaporative water loss and surface runoff and maximizes the storage fraction – that of the soil moisture component (thus generating rain-fed biological productivity) and that of the groundwater storage component (of a potential to become irrigation water and may also support productivity in the dry seasons and drought periods). Such regulation of the water cycle through trees amounts to regulating the tradeoffs between the three rainfall fractions. In the following we address first the regulation of the evapo-transpiration fraction, and mechanisms for compensating evaporative losses, and then the regulation of surface runoff and tradeoffs with the storage fractions.

Tree regulation of the evapo-transpiration rainfall fraction

High productivity associated with low transpiration loss is a characteristic of trees sought by dryland farmers. A critical tree attribute is a trees' water use efficiency – the amount of carbohydrate produced through photosynthesis per unit water transpired. Dryland tree species have acquired high water use efficiency through natural selection, an attribute land users need to consider when selecting tree species for promoting the productivity in dryland agroforestry systems.

With large area of transpiring foliage and expansive and deep water sucking roots tree-dominated ecosystems deplete and transpire more water stored in the soil and groundwater than ecosystems dominated by non-tree plants. Furthermore, water loss per unit area of leaf tissue of herbaceous vegetation such as grass or forbs is often smaller than that from trees (Thurow and Hester 1997). For example, the transformation of woodlands to croplands in the semi-arid zone of Israel reduced the overall evapo-transpirational water loss (Stanhill 1993), and afforestation of non-forest dryland areas in China increased evapo-transpirational) water loss [241].

Where trees exist part of the precipitation falls directly to the ground without hitting the tree (throughfall), while the rest is intercepted and stored temporarily on the surfaces of leaves and barks. From these surfaces it either evaporates (interception loss) or drips from canopies directly to the ground (canopy drip), and/or flows down tree branches and stem surfaces to the ground (stem flow). This "interception loss" may be considerable and even increase where water retaining litter layer exists under the canopy (e.g. an interception loss in two Juniper tree species in USA rangelands, of 26% and 37% of rainfall with added 40% and 60% loss due to litter [242].

The interception induced increase of the evaporation fraction and the associate decrease in the storage fraction of the rainfall, can be offset by other functions of trees in the water regulation service. This offsetting can be achieved through reduction of evaporation by the shade provided by tree canopies (e.g. 92% higher evaporation in exposed than in tree covered patches in semi-arid area in Israel, [243]. Other mechanisms offsetting the interception loss discussed in more detail in chapter 6.2.2 include hydraulic lift and reduced competition for soil moisture with crops and grasses which can't access the water from deeper soil horizons and groundwater which is accessible to many tree species.

Trees may also increase rainfall because their foliage is generally darker with lower albedo (reflection of solar irradiation) than drylands soils which are mostly pale with higher albedo. Surfaces with lower albedo absorb more solar energy, heat up more easily and drive convection of air, which triggers the formation of clouds and rainfall. Mean annual albedo varies in West Africa from 60% in the arid zone to around 15% in the humid coastal areas, a difference attributed to a concurrent increase in tree cover [244]. Increase in rainfall in the northern Negev of Israel has been attributed to reduced albedo resulting from transformation of rangelands to afforested and irrigated cropland systems [245], while Samain et al., [246] attribute increased rainfall in the Sahel to albedo changes.

Tree regulation of the surface runoff and storage tradeoffs

Surface runoff is generated either when the rate of rainfall on the soil surface exceeds the rate at which water can infiltrate the soil ("infiltration excess" surface runoff, occurring mostly in drylands), or when the soil is saturated yet rainfall continues ("saturation excess" surface runoff). Thus, the size of the surface runoff fraction is negatively related to the size of the soil storage fraction, which mainly depends on the soil porosity. Indeed, soils are of loose and aerated texture, due to their organic matter that binds the soil's mineral particles together. The binding creates aggregates with air spaces between them. The size and amount of these pores confers porosity, which determines the rate of water infiltration, and the volume of the water storage fraction that can be retained by the soil. However, this particulate and porous texture of soil which promotes rainfall infiltration also makes the soil vulnerable to the mechanical force of the falling raindrops, which reduce the stability of the soil aggregates, and reduces porosity and hampers infiltration. Depending on the kinetic energy of the raindrops (that depend on their size and velocity) and the degree of topsoil wetting, the soil aggregates may break down, crumble ("slating"), or crack, and fragments can be detached and displaced ("splash effect"). These processes reduce and clog the soil pores thus leading to soil surface crusting, hence to soil sealing that reduces infiltration and initiates surface runoff, which often erodes the soil either in bulk or just leaches away dissolved soil minerals and its organic matter [242, 247, 248]. These losses reduce the soil fertility and its water holding capacity hence the size of the soil storage fraction, while increasing the size of the surface runoff fraction.

It is the soil vegetation cover, and especially its tree component, which stand between the soil surface and the descending raindrop that mitigates the raindrop impact, thus protecting it from crusting, sealing and erosion, and hence reducing or even arresting surface runoff generation. This component of the water regulation service of trees reduces the surface runoff fraction and conserves the water storage fraction of rainfall. A «by product» of this water regulation service of trees is another services critical to productivity, that of soil conservation. It is the large surface area of foliage and the complex architecture and physical structure that contribute to the regulating services of trees, through canopy interception. Part of the intercepted water evaporates (see earlier), what reduces the amount of raindrops that impact the soil surface, and another part loses much of it kinetic energy during its downward descent, as it is dripping though the foliage mass.

The canopy-intercepted rainfall that has not evaporated either drips from leaves and branches to the ground (canopy drip), or is streamlined along barks to create the stem flow. Depending on the amount of rainfall and its intensity, the stem flow drainage may produce concentrated point-source input which may generate surface runoff and soil erosion at localized but stationary areas [249]. As for the canopy drip, it may have a mixed effect on soil and hence on the surface runoff fraction of gross rainfall.

The size and the velocity, and hence the kinetic energy of raindrops that reach the soil surface can vary, depending on tree architecture, canopy density and leaf morphology, and on rainfall attributes. While the proportion of total rain reaching the ground always decreases, the kinetic energy of rain falling through tree canopies, and hence the potential for initiating surface runoff and soil erosion can increase. For example, when the depth of water reaching the ground as tree throughfall was reduced to 28% of rainfall depth, the kinetic energy of rainfall increased (from 18 J/mm/m2 to 32/J/mm/m2, Brandt 1988). Moreover, raindrops can also consolidate the surface soil particles to form a crust, thus reducing infiltration and increasing the risk of surface runoff generation [250]. However, the kinetic energy gained when the drop size of the canopy-intercepted rainfall increases will be lost unless the tree is high enough for the drop to attain sufficient velocity [251]. Thus, by and large, trees are instrumental in providing water regulation service by reducing surface runoff, thus increasing water storage; through canopy interception and jointly with their expansive and deep root systems trees also underpin the soil conservation service.

Conclusion

Compared to other plant forms, trees extract, transpire and evaporate much of the rainfall, and at the same time dramatically reduce surface runoff and hence contribute to increasing and maintaining the soil and the below-ground storage fraction. However, depending on specific tree attributes of the different tree species and the tree site-related ecological attributes, trees may further increase transpiration losses by reducing albedo, reduce evapotranspiration losses by shading, reduce storage by roots' hydraulic redistribution, increase surface runoff by dripping following canopy interception, increase rainfall through reducing albedo, or increase overall water use efficiency of the agroforestry system by reducing root competition with crops.

By and large, it is the attributes of the tree life form that make an individual tree instrumental in the provision of water regulation services critical in maintaining the global water cycle. But the overall contribution to surface runoff regulation and hence to flood and soil erosion control within an agroforestry ecosystem depends on the spatial extent of the tree cover relative to that of the crops. With respect to forests, for example, it has been suggested that in semi-arid and arid areas a cover of 3.5% to 5–6% would suffice for conferring the surface runoff regulation benefits to the rest of the land [252]. Surely, the dispersion pattern of trees may be critical to the agroforestry land user needs with respect to water regulation services provided by the trees. For example, water regulation that increases local storage by reducing surface runoff would be counterproductive for an agroforestry system that depends on groundwater for irrigating crops, but the geological infrastructure suitable for groundwater storage is relatively remote, yet its water is renewed by surface runoff. To sum up, a careful, science- and experience-based design and management of tree species selection, their stand sizes and their spatial dispersions, are required, for balancing the mutual tradeoffs between the three rainfall fractions for optimally supporting the land use specific objectives.

6.4.4 Macro-climate mitigation

Audrey Chenevoy and Jan de Leeuw

The drylands of the world are considered to hold significant climate change mitigation potential through sequestration of carbon and avoidance of emissions. Yet, climate change mitigation in drylands is complex for a variety of reasons. This section reviews the potential for climate change mitigation, the conditions required to make this happen and ongoing initiatives in the drylands of the Eastern African region to implement mitigation projects.

The world's drylands store a significant amount of carbon. Thirty-six per cent of the global terrestrial carbon stock and 59% of the African carbon stock is in drylands [253]. Drylands are also considered to have potential for climate change mitigation through sequestration of carbon and avoidance of emissions [254, 255]. This potential emerges first from the large extent of rangeland systems, which comprise the majority of the African continent. A second reason is the carbon under-saturation of many drylands systems, which is due to land degradation, land use change and burning and this under-saturation offers opportunity for sequestration. A third reason why drylands hold mitigation potential is the potential to avoid emissions from burning and erosion [255].

Significant attention has gone to the potential for below-ground carbon storage. Lal (2004), for example, estimated that the world's drylands could store 1 GT of carbon per year. There is also potential to sequester carbon in the above ground vegetation particularly because this is degraded or absent in many drylands systems as a result of overgrazing, fuel- and construction-wood collection, control of bush encroachment, burning or other land uses incompatible with the development and accumulation of carbon in the above ground parts of woody species. Sequestering carbon in above ground biomass may have its own complexities however, because increased woody biomass may create tradeoffs with other land uses [255].

The Intergovernmental Panel on climate Change (IPCC) (2000) considered agroforestry and improved grazing management as the options with greatest carbon sequestering potential globally. Agroforestry systems rank high in this IPCC assessment because of the trees sequestering significant amounts of carbon above ground. However, sequestration is complex to implement in lands with uncontrolled grazing, fire and active biomass extraction for the production of fuelwood and charcoal. There are examples however, including the *ngitili* in Shinyanga in central Tanzania and the enclosures in the drylands of Ethiopia, where land owners who developed innovative institutions to protect degraded rangelands managed to control these degrading factors and restore tree cover with significant sequestration of carbon in above ground biomass as a result.

Land owners sequestering carbon may consider the option to generate income from the climate change mitigation service they provide. In theory, carbon markets may present win-win opportunities for buyers and sellers of carbon emissions. In practice, however, it is difficult for rural people to tap into carbon markets because it presupposes various skills rural people may not have. These include the technical capacity to enhance C storage in production systems, the capacity for resource users to adopt and maintain land resource practices that sequester C, the ability for dealers or brokers to monitor C stocks at a landscape level, the institutional capacity to aggregate C credits, the financial mechanisms for incentive payments to reach farmers, and transparent and accountable governance structures that can ensure equitable distribution of benefits. Further, while carbon payments may have a potential to increase rural incomes, they may also lead to inequity and expose resource users to social tensions and institutional risks [256].

Ideally the net return from a mitigation project would suffice the farmer supplying the service. However, climate change mitigation also generates non-monetary co-benefits which may include the effects of tree cover on increased productivity of annual crops; income from poles, timber and other marketable tree products; improved family health from tree fruits; availability of fuel and firewood. All those benefits are serving farmers' food security and reduce their vulnerability to climate variability and change [257]. It is important to consider these co-benefits because they may increase the attractiveness of mitigation to the farmer providing the service.

In the drylands of Eastern Africa there are few climate change mitigation projects. The Kasigau Reducing emissions from deforestation and forest degradation (REDD+) project in Kenya protects over 500,000 acres of forest and brings the benefits of direct carbon financing as well as job opportunity to rural Kenyan communities while also securing the wildlife migration corridor between Tsavo East and West National Parks. The carbon credits are distributed equally over the company coordinating and administering the mitigation project (Wildlife Works), the owners of the land and the communities managing the land (see chapter 7.5 for further information).

Carbon credits have potential to create resilience because the stable income from carbon credits tends to buffer the income of the household, which otherwise would fluctuate because of the high volatility of income from livestock and other dryland products. Enhanced incomes, access to credit and more fuelwood, improved soil fertility are significant driving factors behind changes in land use practices in drylands for both male and female farmers. Whether men or women, both value non-cash benefits and developing an innovative land management system would provide space for men and women to come together and engage in decision-making and thus, open up opportunities for collaboration and cooperation [258].

Appropriate institutions are important to ensure proper implementation of mitigation measures. Legal entities representing land owners and service providers are required to formalize the transactions foreseen in a carbon payment scheme. This is easier to accomplish with privately-owned property where land owners have clear tenure arrangements than community owned lands [255]. In case of communally owned lands those providing the mitigation service need to have the certainty of receiving the rewards for the service they provide. Owned lands and a fair benefit sharing mechanism is required to avoid monopolization of the benefits. Parties involved also have to agree on how to verify, measure and monitor changes in carbon stocks. Eventually, building upon previous development work, engaging with pre-existing farmer groups, empowering farmers on the ground by strengthening the capacity of community-based organizations can ensure that benefits reach farmers and are distributed equitably, thus increasing project success. This can only be possible with a strong support of the institutional level [257].

6.4.5 The role of trees in regulating soil erosion

Wolde Mekuria, Kiros Meles Hadgu, Lulseged Tamene Desta

Soil erosion by water or wind affects agricultural production and the natural environment, and is one of the most widespread of today's environmental problems. It results in impacts both on-site (at the place where the soil is detached) and off-site (where the eroded soil is deposited). The consequences of soil erosion include decreased soil productivity, reduced agricultural production, declining quantity and quality of fresh water supplies, increased poverty and political instability [40, 259]. This section synthesizes the extent of soil erosion, the on-site and offsite effects of soil erosion, the role of trees in controlling soil erosion, and the factors that influence the effectiveness of trees in reducing soil erosion.

The Global Assessment of Human-induced Soil Degradation (GLASOD) is the commonly used global map of land degradation [260, 261]. GLASOD estimates a total land area subjected to human-induced soil degradation of about 2 Bha (Billion ha) with 1.1 Bha affected by water erosion and 0.55 Bha by wind erosion [262]. GLASOD further identified important soil erosion hotspots in South Asia, sub-Saharan Africa, Central America and the Caribbean, and the Andean region in South America [262] particularly in semi-arid and sub-humid climates at low and mid-latitudes.

The main on-site impacts of soil erosion include the reduction in soil fertility resulting from the loss of the nutrient-rich upper soil layers, and a reduction in water-holding capacity. In drylands, loss in plant-available soil water-holding capacity is probably the more serious impact of soil erosion because root-zone water-storage capacity can be changed substantially by erosion [263]. Erosion-induced loss in soil water holding capacity is more serious on shallow soils or soils having sub-soils with limited water holding capacity. Losses in available water-storage capacity can result in significant reductions in crop yields and negative effects of erosion on agricultural yields are widespread in the developing countries of Africa and Asia [264-266].

In addition to its on-site effects, detached and transported soil material can give rise to 'off-site problems' including the movement of sediment and agricultural pollutants into watercourses. This can lead to the silting of dams [267], disruption of lake ecosystems and contamination of drinking water [268]. Increased downstream flooding with devastating impact on people, their property and infrastructure may also occur due to the reduced water retention capacity of eroded soils [269].

Land management practices that maintain vegetation covering on the ground are effective in reducing soil loss and erosion. This is because run-off and soil loss are both inversely related to ground cover. Trees and non-woody vegetation increase surface roughness, reduce the energy of the impact of raindrops on the soil as well as the ability of running water to detach and transport sediment [270]. De-Ploey, [271] estimated that soil erosion rates on fields with bare soil are 100-1000 times higher than on fields with a permanent vegetation cover. Williamson et al., [272] also showed that riparian buffer strips and hill slope forestation reduced sediment export by 85%. The importance of soil cover to reduce soil erosion has also been shown in a study where soil loss decreased exponentially with increasing degree of vegetation cover [273-275]. Further, Descheemaeker et al., [276] and Mekuria et al., [277] demonstrated that vegetation re-growth in exclosures has become an important measure to combat land degradation. Runoff production in exclosures, measured using runoff plots [276], is significantly reduced when a degraded area is allowed to rehabilitate after closure. Though runoff is significantly correlated with event variables such as rain depth, rainfall intensity, storm duration and soil water content, total vegetation cover is the most important variable explaining about 80% of the variation in runoff. Runoff was found to be negligible when the vegetation cover exceeds 65% [276]. A study by Tamene and Vick [278] showed that the life span of some of the water harvesting reservoirs in northern Ethiopia could be extended by 50% through appropriate land management and surface cover with trees.

Trees can help reduce soil erosion by: (1) slowing wind and water flows, (2) providing protection from wind and water, (3) holding soil together, and (4) increasing infiltration

[279]. Rainfall interception is considerable in tree or shrub canopies. Mastachi-Loza et al., [280] illustrated that the canopy of native Prosopis and Acacia trees intercepted up to 20-30% of the rainfall. In addition, soil water infiltration rates are greater under canopies as a result of the soil protection from raindrop impact and compaction by the addition of organic matter from plants, improving soil crumb structure [281, 282]. Trees increase organic material levels through the decomposition of the litter they produce, and moderate soil temperatures and consequently improve soil moisture, resulting in a higher infiltration rate beneath the canopy cover [283, 284].

Dryland trees and shrubs also protect soils from wind erosion [285]. Scattered trees and shrubs reduce wind erosion in three ways: (1) it shelters the soil from the erosive force of the wind by covering a proportion of the surface; (2) it reduces the wind velocity by extracting momentum from the flow of the air; and (3) it traps sediment particles. Barriers placed in the path of prevailing winds reduce wind speed and thus reduce wind erosion. Hedgerows of trees and shrubs are particularly effective for this purpose. They should be planted with a range of species to obtain variation in height, densities and level of leaf/branch cover that remains relatively high throughout the year. Shelterbelts allow some airflow which eliminates the unwanted turbulence that occurs behind solid barriers. Although some yield reduction may occur to crops immediately adjacent to shelterbelts and windbreaks, research has shown that there is an actual overall increase in yield of crops that are grown in fields protected by shelterbelts [286].

How could we enhance the effectiveness of trees in controlling erosion? A perennial tree cover protects the soil better against erosion than do annual crops, as the latter leave soil bare and unprotected for part of the year. But trees and shrubs usually require several years to close their canopy, whereas most annual crops provide adequate cover within weeks after planting. During the immature phase of trees and shrubs, there may be insufficient soil cover [279]. Plantations are also vulnerable to erosion at harvesting where a single storm can cause severe soil erosion and degrade the landscape. It is therefore essential to plant trees in conjunction with deep-rooted and fast growing grasses which will also use water, increase infiltration and control flow [279]. If water is a limiting factor for the growth of vegetation, effectiveness of tree to controlling soil erosion can be enhanced by integrating planting of trees with terraces and water harvesting infrastructure and planting trees along the contours. Choosing trees, which allow grasses to grow under them so that water infiltration is increased and the soil is not left bare will protect the soil from erosive rain. Ground cover varies during the life of agroforestry crops. It is lowest at times of establishment, when bare land is highly vulnerable to erosion. Mulching or planting cover crops can help overcome bare soil at tree establishment.

The effectiveness of trees in reducing erosion is affected by differences in root biomass, rate of decomposition of the root system (i.e., the resistance to microbial decomposition), the growth rate, tree density, and species diversity of a stand. Decomposition rate of tree root systems will influence the amount and composition of soil organic matter, which consequently influence the hydrological properties and erodibility of soils. The planting of fast growing trees (i.e., species that quickly form a relatively closed canopy) with large root biomass could help enhance the effectiveness of trees in controlling soil erosion. Tree density is one of the important factors that determine the effectiveness of trees to control soil erosion, as it has a direct relationship with reducing wind speed. Supplementing tree planting with physical soil conservation measures can provide addition value – reduce runoff and erosion and sustain planted trees.

6.5 Cultural services

Maureen Kinyanjui, Mieke Bourne, Jan de Leeuw

The appreciation and adoration of trees has a strong psychological and social foundation in most cultures. Trees feature in all aspects of culture: language, history, art, religion, medicine, politics and even social structure. The variety of cultural values and symbolic functions ascribed to trees are as numerous and diverse as the communities and cultures. Below we describe four of the cultural services that trees provide in the drylands of Eastern Africa.

Religion and spirituality

Dryland tree species are important in religious and spiritual ceremonies and are conserved because of this cultural significance. In many African cultures, the tree such as the baobab (*Adansonia digitata*) features in many myths and tales and consistently reflects a few important symbolic images. The tree stands between heaven and earth and is associated with creation as well as the underworld. The tree is a maternal symbol: a protector and provider. The positive appreciation of trees is related to the numerous goods and services that they provide such as food, water, fuel and materials for shelter, clothing, fences and barriers. The baobab tree is particularly revered as it provides water and food during drought. Other species such as *Boscia* and various *Acacia* play important roles in the traditional oral histories and spirituality of dryland societies.

For the Kikuyu people of East Africa, cutting trees, breaking branches, gathering firewood, burning grass, and hunting animals are prohibited from groves that have the sacred *Mugumo* tree (*Olea africana*). Sacred groves have been protected because of cultural and religious reasons and they also provide certain species of trees which are used to perform rituals, provide medicinal values and support cultural functions such as areas where disputes are settled and functions like burials and weddings take place. These sacred places are revered and cared for by indigenous and traditional people and are often a fundamental part of their territories. Many ethnic groups in Kenya had special reverence for specific trees as meeting points where elders would discuss and provide council for the communities.

Community building

Very strong emotional ties exist between people and elements of natural settings such as trees. Trees often serve as property lines (boundaries) and define the location of a community. Trees and landscapes are shared symbols that become part of the identity and character of a place that foster peoples capacity to work together, become a source of pride and stimulate economic activities [287].

Planting trees to mark boundaries help reduce conflict thus leading to community building. Scarce natural resources can often result in conflict, however, with the introduction of tree regeneration and large-scale projects such as farmer-managed natural regeneration (FMNR) or Evergreen Agriculture, resulting in improvements in food security reduces conflict and leads to community building.

Socially, communities have identified themselves with certain benefits from certain tree species, bee keeping, medicinal species used to make good beer e.g. “Muratina” (*Kigelia sp.)* among the Kikuyu and Kamba communities in Kenya. In some cultures, tree names symbolize events and places. Among the Tugen, for example, several centres are named after the predominant trees in the area. (e.g. Patkawanin a centre a few kilometres from Kabarnet is named after the Patkawa tree). Amongst the Kalenjin, an elder is recognized by the special wood handle he carries in his hand. Further, the Kalenjin flavour milk through infusing smoke from a burning ember of the “sitotwet” tree. This drink is especially popular during celebrations.

Aesthetics

Trees add to the aesthetic value of landscapes by adding colour to an area, screening views and contributing to the character of their environment. In some cases the presence of some green trees in the dry arid lands provides a sign of hope and relief for pastoralists. Open spaces with trees attract more people than open spaces without trees, thus supporting social interactions. (Figure 6.5.1)

Figure 6.5.1 Kenyan Samburu women selling souvenirs to tourists under tree shade.

Recreation and tourism

Tourism is an important sector in the drylands of Eastern Africa because they host a unique assemblage of wildlife attracting tourists from all over the world with significant economic benefits to national and local economies. Wildlife-based tourism is predominantly located in the regions' savanna and grassland biomes and for many it is associated with grazers and grasslands. Yet, trees are an important landscape element underpinning this vibrant sector. First, they provide fodder and energy to multitudes of browsing herbivores and indirectly to the big cats that prey on herbivores. Second, they provide shade, which predator and prey seek hence serving as great places for tourists to spot the animals (Figure 6.5.2)

Third, trees are an important element of the landscape – the flat-topped Acacia (*Acacia* tortilis) and the presence of Maasai people are symbols of the safari experience –enhancing the aesthetic value of the landscape and contributing to the visitors' experience in conservation areas. Fourth, the hotels, tented camps and other tourist facilities that host these visitors are typically located in areas well endowed with trees, such as riverine forests or isolated groves.

Figure 6.5.2 Elephants and acacias, globally known symbols of the Eastern Africa safari experience.

Chapter 7: Resilience at livelihood and ecosystem level: building the case

Introduction

This chapter reviews information on where, and how, trees play a significant role in livelihood resilience. During the second and third day of the write-shop, participants proposed cases of the role of trees in natural resource management across Africa and based on this presented, received feedback about, and refined a series of more than 11 short cases (see table 7.1). These have been further developed and are included here.

Keep in mind the two-tiered approach we are using – one that considers resilience from the perspective of "measures that increase the resilience of the drylands' natural capital to maintain its potential to *sustainably* generate ecosystem services**"** (from chapter 4 Conceptual Framework) while also considering the community capacity to manage the many tree-related products people need to live better, healthier, less vulnerable lives.

Table 7.1 Summary of cases: building resilience with trees in Eastern Africa and beyond

Country: Project Name	Location	Approach	Duration	Scale
7.1 Tanzania: *Ngitili* reviving indigenous community enclosures	Shinyanga region expanding to Mwanza	Farmer-managed natural regeneration/ enclosures	1986 – 2005	350,000 ha+ rehabilitated as of 2005
7.2 Kenya: Domesticating *Melia volkennsi*	Makueni, Kwale Taita-Taveta, Kitui	On-farm plantations with multi-purpose focus.	Since 1990s Now being scaled up	Several thousand small dryland farmers involved
7.3 Eastern Sudan: Securing rights, restoring lands	Eastern regions: Kassala and Gedaref	Community capacity building R&D and policy advocacy work.	20 years	*No scale indicated*
7.4 Uganda: Farmer-managed natural regeneration	Offaka		Ongoing,	Approx 10,000 people trained, Land area unclear
7.5 Kenya: Kasigau Corridor Carbon project	Southern – Taita – Taveta Counties	Carbon financed (REDD+) community projects– Kasigau corridor project Wildlife Works Private co.	1999 – 2008 Phase I 2009… now Phase II	30,000 ha Phase I *Scaling up to* 170,000+ ha in Phase II
7.6 Uganda: Shea nut Project for Local Conservation and Development	Northern & Eastern – Lira, Kitgum, Soroti	Livelihood strengthening / Non-Tree Forest Product (NTFP) extraction	1995 - 2003	More than 2000 producers – mostly women, 50 producer groups
7.7 Uganda: Desert Date	North Eastern –Teso and Karamoja subregions	Protection & natural regeneration of *Balanites ægyptica* / desert date commodity (oil)	2007 – 2012 (some aspects ongoing)	Pilot-scale, number of beneficiaries not clear
7.8 Kenya: Rainwater harvesting & range rehabilitation incl. trees	Machakos, Makueni	Supporting farmer groups on-farm water management	2011 - present	Total land area not known
7.9 Somalia: SahanSaho Project	Adado, Galkayo, Buhdle	Supported by Finnish Somalia Network – Tree Seedling production for communities	5 yrs – from 2012	Implementation in 3 districts, number of HHs not provided 170,000 seedlings planted to date.
7.10 Burkina Faso and Niger: "*Wegoubri'*	NTFP collection	Strengthening traditional adaptive strategies	Since mid-1980's ongoing	Latest estimate +500,000 ha recovered
7.11 Ethiopia: Community Managed Exclosures	Mekelle Ministry of Ag. + Univs. + World Vision	Watershed rehabilitation with trees	1991 – present, ongoing	177 watersheds

7.1 Ngitili: Reviving natural regeneration management in Tanzania

Chrispinus Rubanza, Benjamin Gama and Anthony A. Kimaro

Summary

Ngitili is an indigenous *in situ* natural resource management system practised by the Sukuma people, an agro-pastoral ethnic group from northwestern Tanzania, for enhanced woodland and pasture regeneration. The practice mainly involves protecting vegetation during the rainy season for grazing in the dry season. The system existed as early as the 1920s although was partly halted by colonial era tsetse eradication campaigns, and further discouraged by the 1974/75 'Villagization' policy of massive rural resettlement. Revival of *Ngitili* vegetation conservation to reverse degradation was pioneered by the Shinyanga Regional Soil Conservation (HASHI) programme in 1986 through long-term support from the Norwegian government (NORAD) and the Tanzanian Ministry of Natural Resources and Tourism in collaboration with the seven District Councils across the region. HASHI phased out in 2004 and has been replaced by NAFRAC (Natural Forest Resources and Agroforestry Centre).

An estimated total of 500,000 ha (350,000 ha of natural regeneration and 150,000 ha of agroforestry interventions) was rehabilitated during the 18-year period.

Approach

HASHI developed a participatory extension system and strengthened research through on-station and farmer-based screening trials led by ICRAF to identify best agroforestry practices. These came on top of recognition of the vital role of local management institutions (both traditional institutions and government institutions) in enforcing bylaws to protect regenerated public *ngitili.*

The HASHI programme blended the existing indigenous knowledge on enhanced natural regeneration with new information and techniques on soil and water conservation and tree establishment. Long-term interventions supported capacity building of the local communities, strengthened village governance by establishing natural resources management committees; and training for district staff of forestry and agriculture departments.

ICRAF's role was mainly introduction, testing and scaling up of tested agroforestry interventions. Introduced agroforestry interventions included:

- Improved fodder banks through enriched planting of nitrogen fixing and fodder trees for improved grazing/ fodder value of natural regeneration - *Acacia* spp. (*A. nilotica*, *A. polyacantha*, *A. tortilis*) and exotic species- *Leucaena* spp. (*L. leucocphala* and *L. pallida*), *Gliricidia sepium*.
- Fodder banks to overcome both the low biomass productivity (0.9-1.8 t DM/ ha) of natural grazing lands and low protein quality (30-50 g/kg DM) of native pastures vs. recommended levels (80 g/kg DM) for ruminant livestock performance.
- Soil fertility improvement agroforestry systems using 'fertilizer' trees such as *Gliricidia sepium*, *Leucaena* spp., planted on field boundaries, in hedgerows,

and intercropping/ mixed cropping systems with cereal crops.
- Rotational woodlots (4-5 year rotations) comprising multi-species for soil fertility improvement, fodder and fuel wood production.
- Fast-growing multipurpose species; a win –win situation for timber and soil fertility improvement - *Mellia azedirach*, *Gmellina arborea*, *Samanea saman*, *Cedrella odorata*.

Key elements of Ngitili as a natural regeneration model to build resilience:
- Interventions are farmer-oriented, environmentally sustainable and socially friendly, high ecological adaptation, i.e., indigenous species are well-adapted to this fragile semi-arid ecosystem;
- High sustainability- low (labour) requirements and inputs (planting material) mostly locally available;
- Multiple benefits derived from natural resources management – safety nets fuel wood, fruits, oil and nuts, gum and resins, fodder, thatch grass, poles, herbal medicine, soil improvement, and other ecosystem services;
- High value products – crops, animals, dairy and dairy by-products.

Figure 7.1.1 A private '*ngitili'* of improved pasture under Leucaena (used for poles and fuelwood) in Shinyanga. *Photo: R. Wagner*

Impact
Widespread, documented impacts include reduced pressure on natural woodland resources as fuelwood was now readily available, increased fodder for livestock; improved soil fertility, crop and livestock productivity and ultimately improved livelihoods. As of 2000, largely due to HASHI efforts, re-establishment of *Ngitili* spread from the initial 180 villages to more than 830, reaching 2.5 million people. Incomes in villages where Ngitili were restored rose to twice the average for rural Tanzanians (Monela et al. 2004).

- Landscape transformation - "the country was almost turning into desert"- (J.K. Nyerere, 1984);
- Livelihood impacts - improved incomes from sales from agroforestry-based enterprises (milk, beef, as well as other woodland products like honey and medicinal plants);
- Enhanced crop productivity from improved soil fertility;
- Improved livestock productivity (milk, meat from well-fed cows/ steers).

Table 7.1.1 A summary of the economic and other benefits from Ngitili (2004 US $ equivalent)

Economic value of restored *ngitili*	USD 14.00 per person, per month
National average rural consumption	USD 8.50 per person, per month
Average annual gross value of 16 major natural resource products harvested from *ngitili* (Bukombe district only)	USD 1,190 per year per household USD 700,000 per year per village USD 89.6 million per year across the district
Species of trees, shrubs and climbers found in restored *ngitili*	152 in total
Typical reduction in time spent in collecting natural resources	Collection time reduced by: Fuelwood: 2-6 hours per day Poles: 1-5 hours per harvest Thatch: 1-6 hours per harvest Water: 1-2 hours per day Fodder: 3-6 hours per harvest
Percentage of households in seven districts across Shinyanga using *ngitili* products for various purposes	To diversify diet: 22% To provide animal fodder and forage: 21% To collect medicinal products: 14% To collect firewood: 61% To pay for children's education: 36%

Source: extracted from Monela et al. 2005:3-4, 53, 61, 67-69

Policy implications

- Participatory approach and involvement of local communities in project planning, implementation and review phases,
- Best agroforestry practices worth scaling out to similar agro-ecosystems elsewhere in the Eastern African region (especially with unimodal rainfall) with problems that need similar solutions.

To find out more

Ngitili - An indigenous natural resources management system in Shinyanga. ALIN Eastern Africa.

A Rural Revival in Tanzania: How agroforestry is helping farmers to restore the woodlands in Shinyanga Region. (ICRAF)Trees for Change Series No. 7.

Monela, G.C. et al (2005) Study on the Social, Economic and Environmental Impacts of Forest Landscape Restoration in Shinyanga Region, Tanzania.

7.2 Domesticating *Melia volkensii;* improving livelihoods in Kenyan drylands

Daniel Nyamai, James Ndufa

Summary

Melia volkensii has great potential for building resilience into farmers' livelihoods and in reversing environmental degradation in the drylands of Eastern Africa. Melia volkensii belongs to the family Meliacea and is endemic in Eastern Africa's drylands. It is fast-growing and tolerant to semi-arid conditions (Teel 1985, Mabberly 1997). Melia grows in specific agro-ecosystems in the eastern and coastal regions of Kenya and extends to parts of Somalia, Tanzania and Ethiopia. It grows best at an altitude range of 350-1,680m above sea level, with mean annual rainfall of 300-800mm, under well-drained soils.

Melia volkensii is valued as a multipurpose tree with respect to its high quality and pest resistant timber and non-timber products. This attractiveness has accelerated its over-exploitation (Stewart and Blomley 1994). Its timber quality compares favourably with Ocotea usambarensis and Vitex keniensis. As a result, the tree growers in many areas of Eastern Kenya are striving to grow Melia as a priority plantation species.

However, propagation of Melia has been a major bottleneck and has hindered planting on a larger scale. This is attributed to lack of adequate information on best practices and techniques (silvicultural methods) for public utilization. Considering this challenge, the Kenya Forestry Research Institute (KEFRI) and her research and development partners have been at the forefront of developing propagation, establishment and management techniques of Melia for more than a decade. Scientific methods on propagation (mainly higher germination rates) as well as best practices and techniques for establishment, production and post-harvest processing of Melia timber have been tested, demonstrated and published in a wide range of information materials. The new knowledge and information materials have been the focus of training for hundreds of farmers/ producers, field extensionists and technicians. Similarly, a number of degree-level courses (leading to MSc and PhD research) have been conducted on Melia species. Other key achievements include increased awareness and economic analysis of on-farm Melia productivity, among others.

Approach

Through farmer-based participatory methods researchers and development agencies share knowledge, best practices and techniques, which incorporate farmers' indigenous knowledge. This partnership greatly facilitates learning by doing through practical demonstrations and is intended to ensure that *Melia* tree growing is a successful economic enterprise in Kenya's drylands. This strategy is designed to build the capacity of stakeholders, particularly farmers, in the *Melia* value chain by enabling farmers and tree growers to adapt and own the process and to take full responsibility for implementation. It has benefitted from lessons learnt among each of the partners and facilitated effective linkages with research and extension agents in communicating and sharing their experiences.

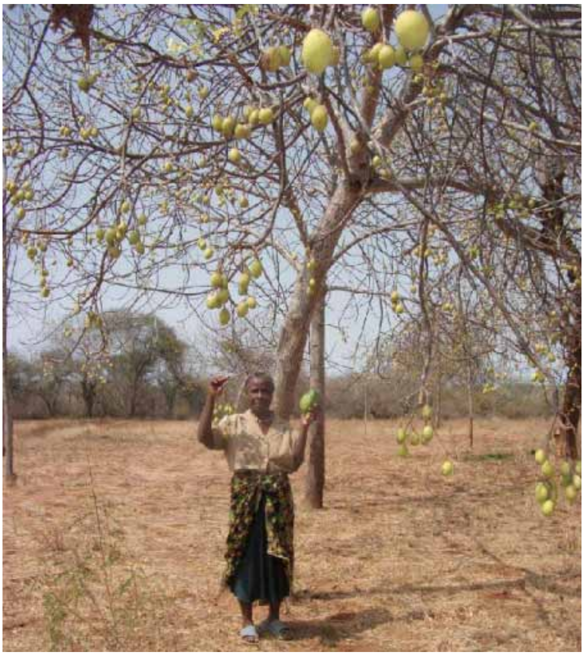


Figure 7.2.1 Mrs. Kasikali, a land owner in Kitui, Kenya standing in front of her Melia plantation.

Impact

Research findings indicate that growing of Melia is a profitable activity for farmers in the drylands. *Melia volkensii* planting contributes to risk reduction and management in the event of total crop failure. Melia can be harvested at between 5-15 years after transplanting. At this age timber value of a single tree is approximately Ksh 12,000 (USD 150). Under optimal conditions, one hectare can have 250 high-quality trees at maturity, offering a potential gross income of Ksh 3,000,000 (USD 37,000) (KEFRI, Information Leaflet N0. 1 & 2 Reprinted in 2012).

In many dryland environments, where field crops normally fail every other year, good and secure financial returns obtained from *M. volkensii* provide resilience enhancing 'safety net' to farmers in years of poor harvest.

Policy implications

Appropriate policies and institutional mechanisms are critical avenues through which sustainable and equitable development activities such as Melia tree enterprise can be based. Such policies are at the heart of the agrarian systems and environmental sustainability necessary for dryland ecosystems today. The user-driven policies and institutional arrangements need to be crafted with coherent environmental sustainability in mind. Similarly, gender considerations and equal-power relations within resource user communities and institutions would contribute to equal access to benefits from Melia. For instance, farmers and tree growers are likely to adopt environmentally sustainable agricultural land use systems and biodiversity conservation strategies when they have clear rights to resources and are confident of future access to and benefits from the resources. In this case, security of land and tree tenure and use right is critical in determining how rural people can secure their livelihoods and alleviate poverty. So is the provision of incentives and empowerment of resource users to access markets, seize new financing opportunities like those in the carbon markets, and harness their collective local knowledge systems of innovation to respond to development challenges.

Owing to the potential of Melia, the Kenyan Government and other stakeholders are presently developing a policy framework to support mass domestication to promote it as a high-value species. This support includes germplasm development, production models, processing and marketing. In addition, many stakeholders are investing in strengthening the capacity of research and development practitioners and producers/ farmers to improve productivity.

To find out more

Beentje, H. 1994. Kenya Trees, Shrubs and Lianas. National Museums of Kenya, Nairobi, Kenya

Kamondo, B.M., Kimondo, J. M., Mulatya, J.M. and Muturi, G.M. (eds) 2006. Recent Mukau (*Melia volkensii*) Research and Development: Proceedings of the first national workshop. KEFRI Kitui Regional Research Centre, 16-19th November 2004.

Kidundo, M. 1997.*Melia volkensii* - Propagating the tree of knowledge. Special issue: Improved trees for agroforestry. Agroforestry Today 9: 21-22.

Muok, *et al., 2005.*Melia production guidelines. KEFRI

Mwamburi, A. and Musyoki, J. Investing in Trees *Melia volkensii (Mukau)* KEFRI Information Leaflet Nos. 1 & 2. Reprinted in 2012.

Schmutterer, H. (Ed.), 1995. The Neem Tree, Azadirachta indica A. Juss and other Meliaceous plants. VCH, Germany.

Turnbull, J.W. (ed.), 1990. Tropical Tree Seed Research. ACIAR, Proceedings N0. 28.

7.3 Securing rights, restoring lands, improving livelihoods: Kassala and Gedaref, Eastern Sudan

Masumi Gudka

Summary

The arid states of Kassala and Gedaref, Eastern Sudan, have hosted up to 1.1 million refugees for over 40 years. Dry forests are key environmental resources for this region and are affected by degradation and agricultural encroachment. Forests in Sudan are important common pool resources, and most are government-owned, while the refugees have no rights or access to these resources. The forests provide local communities and pastoralists with important ecosystem goods such as fuel wood, fodder, emergency foods and valuable commodities (gum arabic and other products). An initiative has been underway for three and a half years to restore and sustainably manage dryland ecosystems for livelihood resilience, through improved governance and management practices. Since early 2010, with funding from the European Union (EC), International Union for Conservation of Nature (IUCN) in collaboration with the Ministry of Agriculture & Forestry, the National Forest Corporation (FNC) and relevant policy and decision-makers, have been working together on this project.

Approach

Rural dryland communities are de facto managers of dryland resources, and are often the poorer and more marginalized citizens within their countries. A focus on rural communities and their landscapes has been adopted to support the most vulnerable groups (women, marginalized, pastoralists), to improve their livelihoods through more secure rights, and to obtain benefits from restoration and markets from forest products. The premise of the project is reversing degradation in drylands and building resilience of communities by ensuring continued provision of ecosystem goods and services that support livelihoods. This is achieved by strengthening governance through training community-based institutions on natural resource management, particularly land, and by treating land tenure systems as the enabling framework.

At the local level farmers and pastoralists are supported to improve sustainable land management practices using participatory approaches such as community environmental management plans and stakeholder dialogues, facilitated by IUCN staff. The project partner from the government, FNC conducts restoration activities to improve the resilience of the forests and surrounding ecosystems. Land tenure arrangements are being strengthened to reduce potential conflicts between agrarian communities and pastoralists, and to ensure equitable benefits from restored Gum Arabic (Acacia Senegal) gardens and woodlands.

Project activities

- Development of Community Environmental Management Plans (CEMPs)
- Restoration activities conducted as a result of the CEMPs planning processes.
- Rain-fed and irrigated agroforestry systems established to provide communities with alternative livelihoods.

- Providing equipment, tools and running workshops to promote processing of non-timber forest products and agroforestry systems.
- Workshops also held to build local capacity to initiate dialogue with decision makers, scientists, members of parliament (MPs) from target areas, local commissioners, line ministries, and the Gum Arabic Association.
- Community exchange visits to build capacity and share lessons on best practices.

Impact

A key impact recorded for the project at this stage is the influence it has had on government processes and methods of conducting community based work. Due to the adoption of participatory approaches used extensively in the project, the government partner and local communities have fostered a collaborative working relationship. The communities are now able to protect and sustainably manage forest reserves and receive support and guidance from their government. Specific impacts on household-level well-being and natural resource usage have not yet been assessed.

Policy implications/relevance

As an outcome of the participatory approach adopted through this project, a new forestry policy with a greater emphasis on participation is waiting to be adopted after the completion of a revised constitution that is currently being negotiated. A workshop was held in Sudan by FNC between the various policy makers and community stakeholders to initiate a dialogue. This was the first time local stakeholders were involved in a government meeting of this level.

To find out more

contact IUCN – Eastern Africa Regional Office: masumi.GUDKA@iucn.org or visit:

http://www.iucn.org/about/work/programmes/ecosystem_management/about_work_global_prog_ecos_dry/gdi_projects/project/

http://cmsdata.iucn.org/downloads/global_brochure___web.pdf

7.4 Farmer-managed natural regeneration in Offaka, Uganda

Pamela Ebanyat, Clement Okia, Samson Gwali

Summary

Farmer-managed Natural Regeneration (FMNR) is a rapid, low cost and easily replicated approach to restoring agricultural, forested and pasture lands. The method is being promoted by World Vision International as a project model in Uganda. FMNR is based on promoting systematic re-growth of saplings from existing tree stumps with the ability to coppice (re-sprout) or by direct seeding in the soil. In Uganda, Offaka and Anyiribu

sub-counties, the practice was introduced in 2010 by Tony Rinaudo, an FMNR champion from World Vision Australia, who came up with the idea in 1983 and 1984 while working in the southern region of Niger.

Approach

World Vision received funding from Australian Agency for International Development (AUSAID) (through its World Vision Australia support office) to implement a three-year FMNR project in Offaka and Anyiribu sub counties, Arua district in Uganda. The Training of trainers (ToT) approach was adopted for purposes of sustainability. A total of 54 trainers were trained at the start of the project on the FMNR technique, its impact on community livelihoods and advantages over tree planting. Case studies from Niger and the Humbo Mountains in Ethiopia were also shared as evidence of successes to the FMNR technique.

During 2010, the TOTs trained a total of 280 farmers, 140 each from Offaka and Anyiribu sub-counties. By 2011, the project engaged a local community based organization known as Ocebu Youth Action for Development (OYAD) to roll out the project interventions to the rest of the targeted areas. During 2013, up to July when this report was written, a total of 10,750 community members (1517 women, 4939 men, 2047 youth and 2247 children) had been trained by OYAD on FMNR techniques including its impact on community livelihoods. Although some of the community members did not have direct access to land, the training served as an awareness exercise to protect community land against bush burning and cutting down of indigenous trees irresponsibly.

Figure 7.4.1 Regenerating tree stumps in a farmer field, northern Uganda

Impact
To date (mid-2013), a total of over 460 farmers are practising FMNR in more than 130 acres of land. The species diversity includes 70 different indigenous tree species, including Adu, Enzuu, Bondo, Bibinya, Mala and Oli as known in the local dialect of the area. However, within the above acreage, a total of approximately 150,000 trees have been pruned and protected.

Four schools within the project area are already practising FMNR on 2 acres of school plots. The re-sprouting trees provide windbreaks for the classroom blocks and protect the compound against soil erosion. The participation of children in tree pruning in the four schools develops their interest to care for the trees as well as transfer the knowledge home as change agents. In addition, the protection of the indigenous trees is providing good shelter to the animals, especially the goats. The farmers who protect the trees have testified of the increase in the number of goats due to increase in fodder.

Policy implications
While implementing this project, the importance of generating a by-law for environmental management was key. The project success would not be achieved if regulations from the local government were not set. In Adraa parish, for instance, communities designed a byelaw, which denounced bush burning, and tree cutting for charcoal burning that lead to environmental degradation. Although the surrounding communities out of the project area have not been trained in the FMNR technique, the project carried out awareness sessions on community radios and the buy-in of the local leaders would serve to reinforce the set by-laws over a wider than targeted area. Communities have also managed to use the local materials and resources to grow indigenous tree seedlings that can survive and thrive in their locality rather than relying on exotic varieties. Adraa parish has become a centre of learning for all other parishes in Offaka and Anyiribu sub-counties.

> "The reality is that policy can take decades to change and FMNR projects should not wait for this. In many countries where FMNR is being successfully adopted (Niger, Ghana and Ethiopia), national level policies are unfavourable for FMNR adoption. However, by working with local level authorities and communities, projects have been successfully implemented, and in countries like Ethiopia, this success is having a strong influence on national level policy."

Source: *Farmer Managed Natural Regeneration (FMNR) - World Vision Institute*

To find out more

The Development of Farmer Managed Natural Regeneration. LEISA magazine.
http://www.leisa.info/index.php?url=show-blob-tml.tpl&p[o_id]=113390&p[a_id]=211&p[a_seq]=1
Regreening the Sahel. Farmer led regreening in Burkina Faso and Niger
http://www.ifpri.org/sites/default/files/publications/oc64ch07.pdf
Turning back the desert. How farmers have transformed Niger's landscapes and livelihoods
http://pdf.wri.org/world_resources_2008_roots_of_resilience_chapter3.pdf
Farmer Managed Natural Regeneration - World Vision Institute
www.worldvision-institut.de/_downloads/allgemein/FMNR_PM.pdf

7.5 Kasigau Corridor REDD+ project in southern Kenya

Audrey Chenevoy

REDD+ project brings climate change resilience to Kenyan communities

Summary

The Kasigau Corridor REDD+ (Reducing Deforestation and Forest Degradation) project is the first carbon offset project in Eastern Africa under the voluntary carbon market. A private company, Wildlife Works Ltd, has been implementing the project since 1998. Carbon credits started being sold from 2009. The area (covering 500,000 ha) with private and community land tenure is located in Taita and Taveta Counties in South Eastern Kenya. The Kasigau corridor is a very important wildlife hotspot since it links Tsavo East and West national parks, which are Kenya's largest wildlife refuges.

The Kasigau Corridor REDD+ project created an economic incentive for landowners and communities within the corridor to protect their forest. Wildlife Works supports landowners and local communities to implement forest management plans that exclude the destructive use of forest resources.

After a successful pilot Phase I (2008–2011), the project expanded considerably in 2010 from 30,000 ha in the Rukinga forest, to 170,000 ha of similar dryland forest, mainly owned by community ownership groups, or 'group ranches'.

Wildlife Works negotiated Carbon Rights Agreements/Easements with the neighbouring community landowners to execute the sale of carbon credits (at approx. US$9 per ton) under the voluntary carbon market. The carbon right belongs to the landowner but Wildlife Works manages them and sells carbon credits on behalf of the group ranches.

The revenues are shared between 3 groups:

- 1/3 for Wildlife Works to cover administrative costs, reimbursement for donors, verification fees, payments for rangers.
- 1/3 for the shareholders of the land in cash as dividends (paid 4 times/year).

- 1/3 for the communities through budget allocation to community groups having income generating activities which they manage themselves.

Impact

This project is very innovative since it is based on income generation activities that create local employment in many sectors such as:

- **Supporting education and health sectors by** funding school fees, building schoolrooms, sponsoring qualified students, providing medical equipment to the community.
- **Making eco-friendly products**: organic (cotton) clothing factory (long-term employment for over 150 people from the community), starting an eco-charcoal factory;
- **Protecting wildlife**: training and employment of unarmed rangers from the community to protect forest (from illegal charcoal burning) and wildlife (bush meat poachers).
- **Job creation**: Wildlife Works employs over 100 Kenyans from the areas factory managers, accountants, head ranger, etc.
- **Assisting farmers**: in partnership with Kenya Agriculture Research Institute, Wildlife Works provides training to intensify agriculture in dryland areas (growing jojoba for oil).
- **Growing trees**: groups learn to grow organic greenhouse citrus trees as a cash crop; the project provides financial rewards to community members who plant trees and protect them for two full years.

Figure 7.5.1 'Green' charcoal briquettes made by a youth group of the Kasigau project

Policy influence

The Kenya Forest Service is now learning from this project in preparation for the implementation of the REDD+ strategy at national level. The benefit sharing mechanism is promosing since very few initiatives have thus far been developed in this area in Kenya.

To find out more:

http://redd-database.iges.or.jp/redd/download/project;jsessionid=179C5B77034DD677574A2AF2CC481DA6?id=91
https://s3.amazonaws.com/CCBA/Projects/The_Kasigau_Corridor_REDD_Project_Phase_II-The_Community_Ranches/The+Kasigau+Corridor+REDD+Project_PIR_Phase+II_FINAL_v4.pdfhttp://www.wildlifeworks.com/redd/

7.6 Resilient livelihoods and the shea butter tree in Uganda

Samson Gwali, Clement Okia, Pamela Ebanyat

Summary

The shea butter tree (*Vitellaria paradoxa*) is an important oil-producing tree species that grows in the drier areas of northern and north-eastern Uganda. The fruits are eaten, usually as a "famine" food during times of drought, while the nuts contain abundant oil, which is extracted and used for cooking, medicinal, hair and skin ointments. Due to its importance and the emerging threat of tree removal to make charcoal, many initiatives aimed at protecting and promoting the tree for improving local livelihoods have been supported by different development agencies. The livelihoods of local communities, especially women, have been improved and conservation of shea trees enhanced. In addition, the Ugandan government has started the Presidential Initiative on Shea Trees to foster conservation and increased use of shea trees and their products.

Figure 7.6.1 Left: Mature shea trees in northern Uganda – once felled for charcoal-making, now protected. **Right:** Shea fruits on a productive shoot. Photos by Patrick Byakagaba, Makerere University, Kampala)

Approach

In Uganda, women and children traditionally harvest shea fruits when they ripen and also collect them when they fall from shea trees and this happens especially during the annual 'hungry season', usually when food stocks are lowest and agricultural requirements are highest. However, low returns from shea nut sales and escalating poverty, and tree felling for charcoal threatens the existence of shea trees in Uganda's drylands. The local people sometimes practise pollarding (removing branches for firewood and charcoal), after which the tree coppices to provide shea nuts in the next 3-4 years.

Figure 7.6.2 Women selling shea oil at the local market.

Given the significance of shea trees to the communities, especially women and children, the Cooperative Office for Voluntary Organizations (COVOL) through the "Shea Project for Local Conservation and Development (1995–2003)" mobilized the communities to form the Northern Uganda Shea Producers Association (NUSPA). COVOL mobilized more than 2000 producers (mainly women) from over 50 producer groups to engage in shea tree conservation and sustainable production.

Another project, the Northern Uganda Shea Nut Project (NUSP), with support from the Swedish International Development Agency (Sida) and implemented by the Export Promotion of Organic Products from Africa, organized women to collect shea nuts for production and export shea butter as a certified organic product to a niche market in the cosmetics industry in Europe and other markets in Eastern Africa.

> "While we would never want the NUSP members to become dependent on any export-oriented activity for their survival, the income provided by access to international markets offers these women a unique opportunity to greatly (and quantifiably) improve their lives and living standards of their families – in terms of nutrition, education, medical care and investment in profitable enterprises of income from sales of organic shea butter."

Source: Shea Project webpage:http://thesheaproject.org/

The European Union (EU) through the "Innovative Tools and Techniques for Sustainable Use of the Shea Tree in Sudano-Sahelian zones " project (2008-2011) funded work at Makerere University to add value to shea tree products. The initiative studied and documented local management practices, genetic diversity, the shea value chain as well as fruiting dynamics. Training was provided to local students at graduate and undergraduate levels, in addition to community level conservation awareness campaigns. Currently, the World Bank is supporting efforts aimed at using genetic markers to select and propagate shea trees from the drylands of Uganda.

Impact

The impact of these shea tree projects includes positive influence on sustainable management of shea trees and dry woodland landscapes. For example, the COVOL/shea project in Uganda covered an area of approximately 100,000 sq. km and worked with over 400 women groups. The women were provided with training and have established their own processing centres, producing for the market and for home use. In addition, there has been increased inclination towards conservation of young shea trees in areas of project intervention in stark contrast to areas outside the zone of intervention. There has also been greater market linkage and access to increased income for the most vulnerable in society. A USAID-funded study estimated that the potential shea nut production in Uganda range from 70,000 to 385,000 tons, translating into 15 to 80 million litres of oil per year. The same study estimated that actual trade in shea nuts in Uganda ranges between 3,000 and 4,000 tons, approximately 800,000 litres of oil per year.

Policy implications

In 2007, the government of Uganda formulated the Presidential Initiative on Shea Butter trees aimed at conservation of a very useful resources in the country. This decision by the President of Uganda was based on evidence that the shea butter tree is over-exploited especially for charcoal and yet it is a very important tree for the dryland people of Uganda. Previous work on shea trees has resulted in shea being given priority research focus in the National Agricultural Research Systems.

To find out more:

http://thesheaproject.org/

Groenewald H. and Dalrymple S. (2007). The experience of the Northern Uganda Shea Nut Project. Edited by Vanessa Dury and Sonia Ra, Saferworld, London, UK.
http://reliefweb.int/sites/reliefweb.int/files/resources/49ADEB6A9B6C4FD2C12573AA00360A69-Full_Report.pdf

7.7 Desert date in Uganda: a dryland tree for food security

Clement Okia, Samson Gwali, Pamela Ebanyat

Summary

Balanites aegyptiaca, commonly known as desert date, is an important food tree found in the drylands of Uganda and many other African countries. The tree produces edible fresh leaves and fruits during the peak dry season (November–March in Uganda) and edible oil is also extracted from the seed kernel. All these products are consumed at household level and also traded by dryland communities. Other potential uses of Balanites are production of bio-diesel from its kernel oil and its various medicinal properties. Realizing the potential of this tree to support resilience of dryland communities in Uganda, two universities (Bangor University, UK in collaboration with Makerere University, Kampala) formed the indigenous fruit tree project with a priority focus on Balanites. [The project began in 2007 with support from the Leverhulme Trust, UK, and has since received additional support from the Carnegie Foundation of New York, the Government of Uganda and the Global Environment Facility (GEF)]. Community-based organizations are now being supported to set up income generating projects based on Balanites products.

Figure 7.7.1 Left: High density of mature Balanites, Adjumani district, Uganda. **Right:** Balanites leaves sold in a local market in Katakwi district.

Approach

The Balanites project aims at unlocking the potential of this versatile multi-purpose tree, and began by increasing understanding local knowledge on use and management of the tree. This was followed by determination of the distribution and population status, assessing the tree phenology, fruit yield and characteristics, studying the local processing and market potential of the major tree products and determining the nutritional value of its products. This research phase was supported by the Leverhulme Trust, UK through Bangor University and the Carnegie Cooperation of New York through Makerere University.

The next phase with support from the Carnegie Cooperation of New York involved product development and value chains and this has resulted in development of leaf powder, wine from fruit pulp and improvement of the oil extraction method. The project has attracted several graduate students from Makerere University who have undertaken detailed studies on extension of leaf shelf life, improving the quality of fruit wine, nutritional aspects of the products as well as sensory evaluation of the wine and leaf powder. Additional support has been provided by the Government of Uganda and GEF to support communities in conservation and processing of Balanites products. Efforts are under-way to support community groups with appropriate tools for nut cracking and oil extraction. Local governments have offered support for community mobilization and enforcement of regulations for conservation.

Impact

Through this initiative, Balanites trees which were being used for charcoal production are now appreciated and being protected by communities. Women have a strong voice in protecting Balanites trees since they are a source of dry season vegetable. Novel products have been developed from Balanites products, e.g. processing leaves into powder (extending their shelf life from 2 days to 6 months) which extends availability of the product beyond the harvesting period. This allows expansion of the market to more distant areas.

The development of nut cracking tool has increased the oil output and saves time spent by women and children on nut cracking. Income from sale of Balanites products is used by household to meet basic needs and establishing alternative ventures such as retail businesses. Because the earnings come at the peak of the dry season when there are few alternative sources of income, it serves as a safety net for these communities and hence provides resilience in this critical period. Studies show that 98% of the households in the rural parts of Katakwi and Kotido districts rely on Balanites leaves and fruits during the 5-month dry season, indicating the contribution of this tree to food security. The Karamojong people in Uganda refer to Balanites as “a valentine tree” literary meaning the tree shows them “love” [=*food*] even during very dry periods.

Policy influence

The initiative has gained support from communities and local governments and has given rise to community by-laws and district ordinances. Adjumani district in West Nile and Katakwi in Teso sub-regions have put in place environmental ordinances, which seek to protect Balanites and other valuable indigenous fruit trees such as shea trees. Communities have also established ways for controlling bush fires that destroy the young leaves just before they are harvested and cause immature fruit fall.

To find out more:

Hall, J.B. and Walker, H.D. (1991) *Balanites aegyptiaca:* a monograph. School of Agriculture and Forest Sciences Publication Number 3. University of Wales, Bangor. http://r4d.dfid.gov.uk/Output/11153/Default.aspx

NRC (2008) Lost crops of Africa: Volume III: Fruits. National Academies Press, Washington, DC. http://www.nap.edu/openbook.php?record_id=11879
Okia, C.A. (2010) *Balanites aegyptiaca*: A resource for improving nutrition and income of dryland communities in Uganda. PhD thesis. http://dspace.mak.ac.ug/handle/123456789/1007
World Intellectual Property Organization (WIPO) (2006) Production of bio-diesel from Balanites aegyptiaca. URL: http://www.wipo.int/pctdb/en/ia.jsp?IA=IL2006000622&REF=RSS
FAO (1992) Minor Oil Crops: Part I - Edible oils. FAO Agricultural Services Bulletin No. 94. http://www.fao.org/docrep/x5043e/x5043E05.htm#Balanites

7.8 Runoff water management for agroforestry in Makueni, Kenya

Alex Oduor, Maimbo Malesu, Paul Kimeu and Mick O'Neill

Background

- Makueni and Machakos counties are situated in the arid and semi-arid lands of southeastern Kenya and face both physical and economic water scarcity.
- Rainfall, which is poorly distributed, ranges from 500 to 700mm per annum with potential evapotranspiration of 1300 to 1500mm per annum. This means that rainfall alone is insufficient to support domestic and agricultural water demands.
- However, there is immense runoff in the range of 1000 to 3000 m^3 per hectare generated each year in these areas.

Approach

The Ministry of Agriculture's National Agriculture and Livestock Extension Programme (NALEP), now transformed to the Agriculture Sector Development Support Programme (ASDSP), the National Drought Management Authority (NDMA), the World Agroforestry Centre (ICRAF), World Food Programme (WFP) and the Kenya Red Cross came together in 2011 to jointly address the challenges of improved water management in drylands. Activities and initiatives include:

- An ICRAF-led assessment of the situation and provision of technical designs for harnessing rainwater for tree nurseries, agroforestry management, domestic use, and food production.
- A joint NDMA and WFP project ('Food for Assets') that provides food to the community in support of their labour for the acquisition of assets such as trapezoidal ponds and trapezoidal bunds. This is in addition to the procurement of non-food items such as tools, plastic pond linings, farm inputs and operational costs.
- Under Red Cross and the Ministry of Agriculture supervision, implementation and capacity building of the communities in runoff water management, especially for agroforestry, poultry, and pasture value chains.

Without such a strong cross-sectoral, multi-agency partnership, a county-wide effort such as this would be much less likely to succeed. Yet in this instance, by bringing all the major players together and tapping their respective strengths, the Makueni RWH initiative is already attracting interest as evidenced by the high number of visitors from within and also outside Kenya.

For optimal performance of the trees and food crops, rainwater harvesting plays a crucial role in mitigating dry spells, drought seasons and supplemental irrigation during critical stages of crop growth. Some of the trees that farmers prefer to establish both in nurseries and farmlands include *Gliricidia sepium*, *Tephrosia candida*, *Faidherbia albida*, *Mangifera indica* and papaya (*Carica papaya)*. Tree establishment takes place in combination with conservation agriculture practices such as minimum tillage, crop rotation and cover cropping.

Impact

- The 2012 report by the Coordinator of Food for Assets Program in Kibwezi, noted that about 5,000 households in Kibwezi District of Makueni County shall benefit directly from 108 on-farm runoff-catchment ponds, with ponds on average having a capacity of 250 m^3 at a cost of USD 1400 for materials (pond lining USD 1200 and improved rope and washer pump including installation USD 200).
- 312,000 tree seedlings have been transplanted to the fields. Farmers are already earning income from the sale of Boma Rhodes grass seed and sale of poultry (Naivasha breed chicks).
- Farmers have been able to reap good returns from the green grams, poultry and horticultural value chains. This has enabled them to improve their economic well-being in such areas as improved housing, ability to pay school fees and improved diets.
- There has been an increase in employment of local artisans to construct water pumps for use at the newly created ponds and water harvesting sites.
- Some tree seedlings raised in the nurseries are sold for income generation.

Policy implication

Given the high demand and success rate for runoff ponds in Makueni County, the government has the opportunity to incorporate runoff water harvesting initiatives in their water development policies and programmes across all the dryland districts in Kenya.

To find out more:

Progress reports to WFP by NDMA and Red Cross.
Progress reports by NALEP to Sida

7.9 SAHANSAHO project, Somalia

Badal Hassan

Summary
As a result of long civil war the terrestrial ecosystems of Somalia are being degraded by continuous deforestation, vegetation loss and soil erosion, with far-reaching ecological, economic and social consequences.

SAHANSAHO project is an environmental initiative financed by the Ministry for Foreign Affairs of Finland and implemented in partnership with Finnish Somalia Network, three of its member organizations and three local NGOs in Addado, Galka'ayo and Buhodle in north and central Somalia. The project is addressing desertification/land rehabilitation, in particular caused by tree cutting for charcoal production in these war-torn regions, in particular caused by tree cutting for charcoal products.

The long-term objective of the project is to increase resilience by tree planting to provide the local communities wood and non-wood tree products and reduce pressure on the natural vegetation.

Project approach
The SAHANSAHO project goal is to:

- Provide 170,000 (multi-purpose trees) seedlings to the communities between 2013-2015
- Train local volunteers on nursery management/tree establishment
- Minimize the plastic waste problem around villages by recycling it as planting pots and as income generating activity (the project buys empty containers from collectors) for the poorest households.

Impact
The project is still young – and one of the first of its kind in Somalia, but has constructed three well-established nursery centres and trained 30 volunteers. It has also created job opportunities for some 100 poor households.

The project also promotes peace building and re-integration of communities, following an innovative co-operative model and strengthened knowledge sharing and social interaction among the three communities in the project areas.

Policy implications
The primary project implementation policy is public involvement/participation and information dissemination.

To find out more:
http://www.somaliaverkosto.fi/or contact: badal.hassan@helsinki.fi

7.10 Sahelian *bocage*: an integrated approach in Burkina Faso

Patrice Savadogo

Summary

- The deterioration of the rural landscape in the Sahel region in general has worsened in the last decades, endangering local populations.
- The creation of Sahelian bocage, or live fence perimeters, in this rural landscape is a way to remedy the problems linked to extensive agriculture and degradation of natural capital.
- The concept is based on the creation of bocage perimeters in a mixed regime for enhancing agricultural productivity, increasing fodder and fuel wood availability.
- The tree-based farming technique adopted in the Sahel helps farmers cope with climate change.

Approach

Traditional knowledge and practices in the Sahel region are first capitalized and improved technologies developed and tested. Traditionally in the Sahel of Burkina Faso farmers have been practicing conservation agriculture for decades. *"In 1979, Yacouba Sawadogo started to use the zaï technique to rehabilitate degraded land"* (Reij et al. 2009). Since then, thousands of farmers have adapted the simple, labour-intensive method of digging planting pits called '*Zaï*'. The dimensions of pits often vary with the type of soil and availability of labour. Pits are dug after the crop harvest during the dry season from November until May. The number of *zaï* pits per hectare varies from 1,200 to 2,500. Both the density of *zai* pits on farm fields and their depth/size are dependent on the quantity of harvestable water. After digging the pits, composted organic matter is added and after the first rainfall, the matter is covered with a thin layer of soil and the seeds placed in the middle of the pit. *Zaï* are especially important for soil and water conservation and erosion control for encrusted soils, and increasing crop yields. Tree seed or rootstock began to germinate or sprout, promoting establishment of vegetation.

Sustainable tree-based land management developed through direct support to farmers. Species selection for live fence as well as farmer-managed natural regeneration is critical for sustaining wood-fuel production.

Impact

These practices are being spread across vast portions of Burkina Faso and neighbouring Niger and Mali, turning millions of acres of what had become a semi-desert in the 1980s until the 2000s into more productive land. The result is a restored environment, increased tree cover, availability of fodder, non-wood forest products and fuel-wood, widespread conservation and utilization of indigenous trees. More specific impacts include:

- Promotion of tree-crop-livestock integration with significantly higher/sustained level of productivity.

- The farmer-managed natural (tree) regeneration techniques adopted in the Sahel help farmers cope with climate change.
- The zai and other technologies on soil water conservation with trees are being spread across vast portions of Burkina Faso and neighbouring Niger and Mali.

Policy implications

- Institutional capacity development for the communities to manage land development and agriculture due to creation of village land management committee that undertake discussion with their municipality and community to secure their common land needs to be enhanced
- The adapted land-management approach has gained interest in many communities, which are organizing themselves to apply the techniques.
- There is a need to combine increased availability of wood fuel with improved technologies for efficient burning of wood fuel.

To find out more

http://www.eauterreverdure.org [*in French*]
Daniel Kaboré and Chris Reij (2004). The emergence and spreading of an improved traditional soil water conservation practice in Burkina Faso. EPTD Discussion Paper No. 114
Reij, C.; Tappan, G.; Smale, M. (2009). Agroenvironmental transformation in the Sahel. IFPRI Discussion Paper 00914, IFPRI.

7.11 Community-managed exclosures in Tigray, Ethiopia

Emiru Birhane and Kiros Meles Hadgu

Summary

Cumulative effects of soil erosion, deforestation and overgrazing caused widespread land degradation across the Ethiopian highlands. In response to the land degradation, rehabilitation measures such as exclosures have been practised by community, government and non-government organizations. Exclosures are areas socially fenced off from wood cutting, grazing by domestic animals and other agricultural activities, with the goal of promoting natural regeneration of plants and rehabilitation of formerly degraded communal grazing lands. The practice of exclosure has been mainly carried out during the last two decades (1991-2013). Priority areas for exclosure are identified by local community representatives, Ethiopian Government development agents, and NGOs closely working together. Community-managed enclosures are mainly practised because of deforestation and overgrazing to rehabilitate degraded areas.

Approach

In the process of closing the area, local people are involved in the delineation of exclosures. In the beginning, the development agents, development committee and the local administration (Baito) jointly identify potential sites for protection based on physical criteria such as shallow depth soil, 80% stoniness, etc. The final decision on the site selection is made during a general meeting of community members. Based on the interests of the local people, methods of protection are decided on at the same meeting (BoANRD 1996). In addition to the physical criteria mentioned above, additional site selection criteria include socio-economic criteria that selected sites are not too close to settlement areas, and are not to be used for grazing. Exclosures are protected using guards who are assigned by the villagers because exclosures are not fenced, to keep establishment costs low. The users of exclosures contribute money for the salary of guards. In some cases, guards work on a food-for-work basis, mainly provided by World Food Programme, for protecting the exclosures under conditions of highly food insecure areas (Yayneshet et al, 2009).

Impact

Converting degraded grazing lands into exclosures is a relatively low-cost land management option with many benefits: halt land degradation, reduce run-off/soil erosion, improve the micro-climate, water infiltration, restore soil nutrients, sequester carbon, provide livestock fodder, fuel wood, and thatch grass for house construction and enhance biodiversity.

Over a period of 20 years, more than 1.5 million ha of land has been rehabilitated in Tigray, and the sequestered carbon was 246 kgha^{-1}, total soil nitrogen increased by 7·9 kg- ha^{-1} and additional available phosphorous stocks amounted to 40 kg ha^{-1}. The Net Present Value of exclosures ecosystem services under consideration was about 28% (USD 837) higher than alternative wheat production. When all benefits are taken into account, exclosures provide higher benefits than other agricultural land use, e.g., intensive cultivation or livestock grazing. Exclosures provide substantial opportunities to mobilize the local communities in efforts to rehabilitate degraded communal lands, given that more than 75% of households had a positive view on exclosures effectiveness to restore degraded soils and vegetation. About 2 million people have benefited from the community-managed initiatives. The community owns the technology and does the promotion by themselves.

Exclosure contributed to the change in vegetation cover from 3 to 11%.

Figure 7.11.1 Land use land cover change after the placement of community managed exclosures (Photo by Land rehabilitation team)

Policy implications

The community-based initiative influenced the revision of agricultural policies in Ethiopia to become a conservation-based agricultural and rural development policy and strategy. This successful community initiative contributed to a national strategy called Climate Resilient Green Economy (CRGE), which considers trees in forestry and agroforestry as one of the pillars contributing to the country's economy. The community based by-laws related to the protection and management of the exclosure was recognized by the judiciary and influenced the extension systems in the drylands of the country. It is also considered as one of the tools for sustainable land management being practiced in 177 watersheds throughout the country. Success of exclosures is closely related to the issue of benefits and their equitable distribution among community members, which has helped to develop sense of ownership security. The emergence of exclosures as an alternative land management strategy is a proven cost-effective management option to counteract degradation of the environment, while at the same time providing long-term economic benefits for the local community.

To find out more

R. Aerts, J. Nyssen, M. Haile. 2009. On the difference between "exclosures" and "enclosures" in ecology and the environment. Journal of Arid Environments, vol. 73, no. 8.

7.12 Conclusion

When reading the project case studies there are many examples of how trees provide or increase the resilience of livelihoods of poor drylands people. These include the following:

1. The Ngitili system provides grazing resources for animals and foods from trees as well as opportunities to collect wood fuel during the dry season, all of which enhance the resilience at household and village level.
2. Small-scale stands of *Melia* on individual farms, once mature, offer the opportunity to harvest and market wood resources in case of drought or when the need arises.
3. In Sudan, the community level environmental management plans and restoration activities have resulted in greater access of refugees to state-owned forests allowing people to benefit from the resources in these dryland forests. This is likely to create resilience, however, the impact of this has yet to be assessed.
4. While farmer-managed natural regeneration offers multiple benefits, in the Uganda case, a full assessment of livelihood impact - though in process - has not been published.
5. A steady flow of carbon credit revenue to land owners in the Kasigau carbon sequestration project helps stabilize household income and thus enhances resilience through its effect on the financial capital of the livelihoods. Further resilience enhancing benefits are likely to accrue but remain to be assessed.
6. Shea butter and Balanites, two trees which provide food and income during the dry season, contribute to more resilient livelihoods where there are few other

options to acquire food and income during the dry season.

7. Water harvesting in drylands raises cropland productivity and speeds up the establishment and growth rate of trees on farm. The latter is a prerequisite to benefit from resilience provided by trees.
8. The Sahansaho project is still young, its community approach enhances the social livelihoods dimension.
9. Sahelian bocage enhances resilience through water harvesting and tree regeneration techniques. While it is obvious that Zai enhances resilience, the text is not specific enough to say more about the tree-related resilience enhancement.
10. Community-managed exclosures in Ethiopia enhance resilience while restoring land and providing goods that may be collected during the dry season or drought.

From the above it is clear that significant resilience may in fact be provided by the activities of these projects. The above overview further shows that projects have information to infer resilience offered by provisioning services, but most of the projects lack information to make the case for resilience offered by supporting, regulating and cultural services. This lack of articulation and providing evidence for resilience is understandable because the concept of and emphasis on enhancing household or community resilience is relatively young.

To ensure better documentation of resilience enhancement in future projects we propose including resilience enhancement as an integral part of project deliverables; second, plan how to collect data and compile evidence of resilience enhancement as part of project M&E activities and third; ensure attention to report on resilience-building of a wider range of ecosystem services than ecosystem goods alone. Finally, a concerted capacity building effort aiming at project staff and communities would be required to achieve this.

In several projects the duration has been just a few years, but in others, we can speak of decades of experience in bringing back the productivity of landscapes to levels that support growing populations. These are the efforts that warrant closer assessment for their resilience-yielding ability, the *how* as well as the *why.* Not enough emphasis – especially at the planning stages – may have been given to maximizing the many ways trees add long-term value in terms of food/fodder/fuel and fibre, not to mention the many systemic benefits of wind/dust/erosion/flood amelioration to the dryland environment. Alternatively, this emphasis may merely be implicit, versus explicit in project-level design.

Yet it is clear that there are large pools of experience and local knowledge in every country that can be drawn on where and when needed. Though only a small start, this chapter might serve as the beginning of a more systematic effort to document and share such knowledge, especially among other practitioners of the art of creating '*tree-silience*.' In annex 1, we pull together write-shop participants thinking about what it takes to achieve large-scale benefits by integrating trees into the game plan.

Chapter 8: Seeking scalable solutions

Jeremias Mowo, Anthony A. Kimaro, Kiros Meles Hadgu and Bob Wagner

What do we really mean by 'scale' and the word 'scaleable'? No project comes with 'handles' that you can simply 'grab and drag' to make it fill a larger space or have a wider impact than originally hoped. But some projects are better designed to be enlarged – even without equivalent enlargement of cash inputs – than others. And some – despite initial challenges – go on to have a ripple effect that far exceeds the scope of the initial effort. This section outlines the elements identified by write-shop participants that give a particular approach or project the potential to have a large-scale impact.

A good example comes from south central Niger (Zinder and Maradi regions) – where the spontaneous spread of farmer-managed natural regeneration (FMNR) as an explicit tree-management and crop-yield enhancing strategy has expanded dramatically in recent decades, impacting millions of hectares of formerly degraded land.

Box 8.1 Farmer-Managed Natural Regeneration (FMNR) in Niger

"Although no study has systematically quantified the impacts of FMNR, Larwanou and Adam (2008) have made a useful first step in this direction. If the number of trees has increased by 40 trees/ha (trees of all ages) on a scale of [approximately] 5 million ha, then FMNR has added about 200 million new trees to Niger's tree stock. Trees affect local climate, crop growth and yields, soil fertility, and the availability of fodder, fruit, and other non-timber forest products. Larwanou and Adam (2008) assume that every tree produces an average value of $1.40 per year in the form of improved soil fertility, fodder, fruit, firewood, and other produce. This would mean an additional value of at least $56/ha/year and a total annual production value of $280 million."

Source: Reij, C.; Tappan, G.; Smale, M. (2009). Agroenvironmental transformation in the Sahel. IFPRI Discussion Paper 00914, IFPRI.

Some benefits from trees are brought to scale more easily than others. The FMNR discussed above has been spreading more or less spontaneously without little outside support, an example of an innovation which is so appealing that it crosses a threshold, tips and spreads like a wildfire. While Malcolm Gladwell popularized the concept of tipping points, it has been relatively unused in the context of scaling of agricultural innovations. During the write-shop one group reflected on and discussed the factors affecting the scaling of interventions.

Group discussions on the challenge of achieving scale during the write-shop identified several main factors that – when present – allow a given initiative to expand to a much larger area: tens of thousands of people participating and benefiting, or even millions, versus hundreds – and hundreds of thousands of hectares being improved with increased tree cover. A brief summary of these follows.

Scalable factor 1. Community ownership coupled with secure land/resource tenure and access

Perhaps the single greatest deterrent to better land management and tree establishment across the Eastern African region is the long history of insecure land tenure and unclear (changing government regulation) status of resource rights. There is, however, a trend toward greater community engagement in policy setting on land/resource tenure – i.e. bottom-up, not top-down, though by no means an easy thing to achieve.

Regarding the method or technology itself, a self-replicating local initiative (e.g. '*zai*' in West Africa) will be far more likely to spread than an exogenous one. Having said this, probably the most widespread self-replicating approach to trees and resilience in dryland Africa (farmer-managed natural regeneration) was initiated by an outsider and fine-tuned with help from farmers.

Scalable factor 2. Strong local extension capacity

Research projects generate (new) knowledge and technologies but these can only be scaled up through extension services (either farmer-to-farmer, government, or a combination of both). It is important to have a strong feedback and exchange of experience between research and extension staff, the research bringing in new options that benefit people, with the extension people reporting back to the research community what works and what doesn't.

Strong expertise in a range of tree-related management skills are important for scalability

Innovative capacity of the extension agents and champion farmers to adapt the technologies to local conditions is also very important. Strong communication skills for the extension staff and researchers are important for awareness raising and capacity development and building.

Scalable factor 3. Linking tree products to markets:

- Sustainable availability of planting materials,
- Proven + available value-adding technologies,

Many tree species in the drylands have under-developed market potential that can benefit from fair-trade. Creating a competitive market for tree-based products provides financial incentive for conservation and adoption (see case study on Shea [section 7.6] from Uganda and Box 8.2 below).

Adding value to tree products (processing/packaging/meeting international standards for quality), to scale up the economic returns, is always a challenge, but usually well worth the investment.

Scalable factor 4. Linking agroforestry with human food/nutrition/health security – tie in with established health services, and/or local education systems

Many dryland trees have high nutritional value (*Adansonia*/baobab is an excellent example[21]). Some of the trees in the dryland produce edible fruit during periods of food shortage therefore offering a measure of food security (another example is *Balanites aegyptica*). See Box 8.2

Box 8.2 Wild Living Resources: A community approach to sustainable use of trees and livelihood diversification

> Wild Living Resources is providing the first sustainable harvesting model for livelihoods, healthcare and biodiversity conservation in East Africa. Located on the Wild Living Resources business park near Kilifi, some 160 species of medicinal species are being sustainably harvested, processed and supplied into the Kenyan commercial herbal clinic market since 2009. The Ufanisi Herbal (a registered CBO) partners with Wild Living Resources to offer training and knowledge for sustainable use of medicinal trees/shrubs to local harvesters of medicinal materials. Certified single species herbals are purchased and marketed into the local commercial herbal clinic sector. This initiative safeguards the natural resource it relies upon and ensures the continued viability of an important source of health care in Kenya.
>
> East African medicinals: The demand for traditional herbal medicine continues to rise throughout East Africa, particularly in areas with limited access to medical care. However, increasing demand exerts pressure on natural resources as medicinal harvesters compete for wild sourced material. This leads to declining populations of medicinal tree and shrub species, further diminishing natural resources, deforestation and possible loss of indigenous knowledge related to the use of medicinal plants in primary health care.

Scalable factor 5. Government buy-in/political will

Clearly, government support for – or direct involvement in a dryland resource management programme will have a strong influence on the size of an area that can be reached. Even where departmental resources are stretched, there are ways public sponsorship can give greater weight to any NGO-initiated, or private sector effort. Many United Nations (UN) agency and bilateral donor programmes channel special funds (e.g. for climate change adaptation work) through the line ministries.

However good interventions, can rarely be scaled up without the support of local and central governments. In contrast, restrictive policies on land use/forest management may interfere with reaching a much larger number of beneficiaries with resilience-oriented training and assistance.

[2] "Nutritionally speaking, the strange chalky powder from a baobab fruit can be considered nature's gift to natural food fortification. The dry, soluble flour provides a simple way to add protein, carbohydrate, energy, fibre, provitamin A, vitamin C, several B vitamins, calcium, phosphorus, and iron to other foods even in remote areas where delivering those by other means is difficult. Moreover the protein has an excellent amino-acid profile, including good quantities of such essential vegetative rarities as lysine, methionine, cystine, and tryptophan. In principal a readily available homegrown means for reducing malnutrition on a long-term and large-scale level throughout much of dryland Africa." *Lost Crops of Africa, p. 36*

While some may see obvious advantages from involving government sectors throughout the planning and implementation stages as project partners, others might argue that it is too cumbersome or time consuming. It is less a question of *if* such partnerships are worth the investment, but *how* to most effectively go about creating and managing them.

Scalable factor 6. Address knowledge gaps (know what we don't know)

To refine the technology 'packages' so they are less costly, make the most of local resources and skills, and incorporate new information (perhaps a direct outcome of the field work with trees and community groups) should be a key aspect of any scale-driven programme.

Knowledge leads to better management. It is what good monitoring and periodic assessments are all about. Yet so often evaluations (the proverbial mid-term and close-of-project assessment) fail to capture innovations and steer subsequent planning processes in a scale-oriented way.

Knowledge is still limited and there is need to expand and broaden the options and include other indigenous wild species.

We should note that there is already a broad, and growing documentation and expertise on topics like farmer-managed natural regeneration, community-based natural resource management (including trees) and other cross-sectoral initiatives (some of which – like the SIDA-funded Victoria Basin initiative, are long-term) to strengthen adaptive and resilience strategies. However, until very recently the importance of addressing resilience in dryland development project/programme planning and assessment was largely missing.

Unfortunately, much of the related literature is difficult to access, or has been written only for the academic community, and not the general public. See the next chapter: Closing the Knowledge Gaps for a more detailed discussion on this issue.

While the write-shop participants represented a small sub-section of the agencies who are working to increase the scale of their impact, there are many others involved who were not present – but whose knowledge and experience has not been overlooked.

Chapter 9: Closing the knowledge gaps

Bob Wagner, Jan de Leeuw and Mary Njenga

"We shall not cease from exploration, and the end of all our exploring will be to arrive where we started and know the place for the first time."

"Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?"

T.S. Elliot

This chapter is an attempt to clarify the unknowns about building resilience with trees. Many emerged during the write-shop discussions. Some gaps in our individual awareness were eliminated as we shared experiences, yet many more were revealed as questions arose. Some of these were technical in nature. Others were economic. One working group prepared a useful list of existing policy gaps. However, to avoid the 'long bullet-list' syndrome, we have categorized the gaps that were most prevalent, and limited them. The intent is to provide pointers to, and focus for the essential work that needs to be done. We consider this section a 'work-in-progress', insofar as we always end up with more questions than answers as we delve into such diverse and rapidly evolving topics as trees – Eastern Africa drylands – and ever-adapting human life-ways.

As mentioned, the knowledge gaps are organized into four categories. First comes the knowledge that is required by farmers and development practitioners on the resilience that could be provided by trees. Second the knowledge on who is doing what and where in managing knowledge, or the 'knowledge management' gap. Third, the knowledge on policies and institutions that are required to make promising interventions work. And last but not least, the science to provide evidence on resilience that can be provided by trees. It might come as a surprise to place the scientific knowledge gap, but there is a good reason for this. Placing the demand for knowledge first promotes a demand-driven perspective on research.

Category 1. What needs to be done to increase skills and capacity now; e.g. a 'best approaches' guideline to building resilience using trees.

What advice/training is needed most on introducing trees for greater resilience in drylands? In addition – who needs it, and for what purposes? CSO/CBOs have very different needs from national or international NGOs, whose needs differ (though less so) from under-funded government extension agencies, while the research community, often well-resourced in comparison, defines their needs in more specialized terms. Aha. We have not even mentioned the dryland 'champion' farmers or pastoral group leaders? Of course, their needs must come first, never last. But do they, in practice?

Given the lack of insight and evidence on resilience and trees there is need for information on resilience that can be provided through the whole range of ecosystem services described in chapter 6. This would include information to enhance resilience from provisioning services that would include the supply of good quality germplasm resources, their propagation and knowledge on phytosanitary and disease control, as well as knowledge on how value addition and market demand and opportunities might increase resilience. To avoid over-emphasis on tree products-related resilience, there should also be information provided on the resilience emanating from supporting and regulating services. The latter (natural resource management) message is much more difficult to get across than the first. It is vital to stimulate proper tree resource management to enhance resilience. The NRM perspective – i.e. fostering regulating and supporting services – should get equal if not greater attention compared to the direct resilience benefits that can be derived from trees.

Category 2. Knowledge management (KM)/sharing gap: who is doing (or has done) what – at the project level in each country?

There is a real and pervasive disconnect between the knowledge held by the research community (which circulates mainly among research scientists or students) and that of development practitioners. On top of this is the challenge to integrate the equally important knowledge held by policy-makers (on unhappy constituent needs/demands etc.), which typically is not published, or even available outside government offices.

This is another different level of 'knowledge gap' that rarely gets addressed [even during write-shops]. The research and scientific community hasn't had the time or interest to study/learn about the current policies and many progressive policy initiatives underway. As a result – they are assumed to be somehow 'lacking' or even absent. Meanwhile, the parliamentary and public service communities – likewise – have little time (or patience) to pay attention to the copious reports and publications coming from the research community. Essentially they speak different languages, and no-one has the funds or time to translate, much less listen closely.

Where to begin?

A well-structured KM set-up does not exist for making existing drylands+trees+resilience projects, recent studies, emerging policies *much* easier to find and follow. The appropriate institutions must be called upon to support the essential work of summarizing and classifying (scale, cost, duration, etc.) the best efforts.

An initial start on closing this gap was made (during the write-shop) in preparing the summary table (see Section 7.1) for Chapter 7 and also the Information Resources annex of this report. Much more, however, needs to be done.

Category 3: Policy Gaps

Appropriate policies and institutions are instrumental in allowing people to reap the benefits from the land resources that they own, use and manage. Current focus of policy and institutional analysis and associated knowledge management regarding trees in drylands focuses on the issue of how these institutions hinder communities from benefiting from trees and what institutional change would be required to prevent this. Such analysis has been undertaken from the perspective of intensification of land use and intensification of the use of tree resources. Thus far there has been no attempt to consider policies and institutions from a resilience perspective and there would be a need to develop knowledge how existing institutional arrangements affect the enhancement of tree-based resilience.

First, can we say that we (all those concerned with trees and drylands development) are up-to-date in our awareness of current 'de jure' (if not de facto) forestry and related NRM policies in the countries where we work? How many readers will confidently reply 'yes' to this question?

For example, here are two excerpts (Box 9.1; Box 9.2) from the Uganda Forestry Policy (2001). Although it does not specifically address the drylands (a small proportion of the country, compared to others in the region) it is progressive in reference to the role of civil society.

Box 9.1 *The role of NGOs and CBOs [page 16]*

> Non-Governmental Organizations and Community-Based Organizations can provide a pivotal role in mobilizing and sensitizing local people, in strengthening civil society and in supporting their active participation in the management of forests and trees. In circumstances where government advisory services have had a limited ability to reach rural communities, NGOs and CBOs have been successful in supplementing the efforts of the public sector, in ensuring that the concerns of the underprivileged are incorporated in national development processes. 2001

Box 9.2 Policy Statement 6: on-farm forestry [page 25]

> The government will promote and support on-farm forestry in order to boost land productivity, increase farm incomes, alleviate pressure on natural forests and improve food security. There are important opportunities for tree farming on private land, for firewood, poles, non-wood products, fruit trees and even timber. This may be in the form of woodlots, agroforestry, silvi-pasture, management of natural trees on farm or small-scale commercialization.

One suggestion: Identify a 'standing committee' among write-shop participants willing to work (jointly) on any of the above selected knowledge gaps. But here we are getting ahead of ourselves, see the next chapter.

Selected policy gaps raised by the "technical issues" write-shop working group:

- Policies to encourage incentives e.g. subsidies for farmers on timber, fertilizer, seed so that they can produce more trees. Linked to policies on markets: lobbying for local and international markets.

- Policies on carbon marketing: Formalizing the carbon finance market e.g. carbon financing, and policies that encourage homemade/domicile financing structures.
- Policies on taxation: This is two-fold: First, to encourage low scale taxation which is pro-small-scale farmers to encourage tree planting. Secondly, to increase taxation for industries that pollute.
- Policy for encouraging private-public partnership for environmental management
- Robust policies on facilitating knowledge management and information sharing that advances inter-sectoral coordination.

Category 4. Trees in drylands science gaps

The above three knowledge management activities are constrained in their ability to generate new knowledge on resilience that can be offered by trees by limitations of project aims and duration, mandates for restricted geographical areas, lack of resources to collect and analyse data and the objectivity and reliability of information derived from this. The scientific community has the capacity to provide quantified, verified and trustworthy information and knowledge about the multiple benefits from dryland trees and *how* they provide resilience. This gap extends beyond 'pure science' and must include the (probably endangered) tree wisdom held by elders of communities living in eastern Africa drylands. Like the excellent book Lost Crops of Africa: Volume III: Fruits (see http://www.nap.edu/catalog/11879.html) but with a dryland tree focus, here is a 'best-seller' waiting to be written.

Where specific trees have been the topic of organized research and/or well-funded promotion initiatives, retrievable published data and sound knowledge exist on their biophysical and agro-ecological aspects. See Box 9.3 for examples. While this knowledge generally focuses on the benefits that trees provide in normal situations, significant knowledge gaps exist regarding the benefits from trees in providing resilience during drought and other natural hazards. There is an interesting research agenda to be developed around this theme that needs urgent attention. Box 9.4 provides an overview of several possible hypotheses. A first step would be to consult the stakeholders mentioned under categories one to three to review these hypotheses and further prioritize the research.

Box 9.3. Scattered knowledge - a few examples

Shea tree – An interesting socio-economic assessment of shea butter projects (which are numerous!) across several countries – looking at a range of feasibility/women's empowerment issues- is the MS thesis by Karin Vermilye, University of Montana, 2004. Granted, this paper is in the 'grey literature' realm – but is clearly written, and of value in planning any scaling-up exercise dealing with this fashionable and 'fair-tradeable' dryland species.
http://www.cfc.umt.edu/grad/degrees/ICD/pdf/Vermilye.pdf

The health benefits of Baobab fruit
http://www.baobabdirect.com/newsitems/2002_06_HealthPropertiesOfBaobab_UNIV_Ferrara.pdf
The venerable Baobab tree is among the most widespread across Africa's lowland semi-arid regions. Yet outside of a few selected places (mostly West Africa) its role in supporting millions of households has only recently drawn attention- an opportunity for collaborative action?

Wild 'famine foods' in general-
http://reliefweb.int/report/ethiopia/wild-food-plants-southern-ethiopia-reflections-role-famine-foods-time-drought [2000]

Box 9.4 Candidate hypotheses for consideration for further research

1. Trees produce food during the hungry season at the end of the dry season when cereals and livestock products are not within reach for many poor people. Evidence for this was provided in Section 6.2.1 (food and nutrition) and section 7.6 (Shea tree case). This appears a very interesting, plausible and possibly more common pathway to resilience but the evidence is scant. Clearly more research on the benefits of trees during the hungry season is required to support this impact pathway.
2. Trees continue to produce ecosystem goods where livestock and annual crops fail to do so. The underlying premise is that drought suppresses the production of trees and their commodities to a much lesser degree than that of livestock or annual crops. This argument was made in chapter four; research is required to support this hypothesis.
3. Tree resources such as wood accumulated in pre-drought years can be harvested, used and marketed to support livelihoods during drought. While this appears evident we found little evidence for this. Knowledge gaps exist around the importance of tree products during drought as well as how their exploitation during drought affects the sustainability of the provisioning of other ecosystem services by trees.
4. Tree resources are assets, which are not easily lost during drought, as mortality rates of dryland trees are low. The consequence of this is that the population of trees capable of producing commodities remains unaffected during a drought. This contrasts with livestock where mortality may be very high and it may take five to seven years before herds reach their pre-drought stocking density. While it is plausible that trees survive drought better than other livelihood supporting assets, we have no evidence of drought-induced mortality rates of trees in the drylands in Eastern Africa.
5. Trees increase production of the ecosystem while they bring up and fix nutrients and manage to use water resources not accessible to non-woody species. The increased production resulting from this strengthens livelihoods and thus enhances resilience.
6. Trees and other protective vegetation conserve soils, while controlling erosion, which has the effect of maintaining a soil with sufficient soil moisture capacity. Without vegetation cover soils ultimately erode and lose their water holding capacity, greatly reducing resilience.

We close this section with an appropriate quote from Chris Reij, Senior Fellow at World Resources Institute.

"There is an urgent need to mainstream sustainable land management in national policy frameworks, but that means also convincing ministers of Finance and Economics [who allocate the funds]....and this will be a lot easier when we have hard data to show that it is economically rational to invest more in drylands. But such data are scarce so we have to go out and collect them. If not we can't mainstream understanding, which is needed to get commitment and action."

Chris Reij, FRAME Forum on Food Security and NRM.

Opportunities to act

Once the overall need for better knowledge-sharing on the roles of trees in resilience is more widely acknowledged (a goal this report can help address) we can individually re-focus our efforts on those areas [or categories of knowledge gaps] we are likely to have the most influence over. The following chapter offers a short description of several possible initiatives – all of which, if carried out, could serve to deepen our collective knowledge, while taking the vital resilience-building capacity for agroforestry in Eastern Africa drylands to the next level.

Chapter 10: Opportunities for action

Bob Wagner, Mary Njenga, Jan de Leeuw and Mick O'Neill

What opportunities exist to transform the knowledge and momentum gathered during this write-shop into further action? Most of the options described here came from discussions (both plenary and inter-personal) during the write-shop. While no special 'working group' was assigned to develop this section, the report editors have taken the liberty to formulate a shortlist of potential activities. Our intent is to plant a few seeds with the hope that some will germinate and sprout in the coming months. For coherence with earlier sections the actions have been categorized under four main headings that were used in chapter 9.

1. Building local skills/capacity on trees and resilience integration

- Make the communication products generated by the KNOWFOR – ICRAF initiative available to all known dryland-based Community Information/Resource Centres [e.g. those with whom the Evergreen Agriculture program is working, the dozen+ run by Arid Lands Information Network – Eastern Africa, other NGO networks, etc.] to ensure this report gets widely circulated *at the field level*. ICRAF is committed to avail the knowledge products to these networks and will allocate resources to allow feedback and for monitoring purposes.
- Community based resilience analysis (CoBRA) in various regions to help communities identify good disaster risk reduction practices and internalize the term "resilience" in their specific contexts. The analysis will also help communities value the role of trees in providing supportive ecosystem services as they contribute to climate change adaptation and mitigation.

2. Knowledge management actions

For those (of us) from within the NGO community, consider:

- Forming a 'community of practice' at the institutional level to achieve better knowledge sharing among colleagues (also across country/regional boundaries) on high-priority – high potential drylands+trees=resilience topics and projects.[3]
  For example: when an ongoing project such as the Uganda Shea Tree and FMNR projects prepares a summary report with new impact data, this can be shared quickly via the web [email/DropBox] and foster ongoing dialog.

- Promote more frequent media coverage (in a *positive,* not *negative* context) of champions [e.g. government and/or NGO project/programme leaders] of dryland resilience who have the capacity to tell their stories and share what they are doing locally.

[3] To formalize it on-line, the forum could be a Google-group [= simple list-serv] that allows quick distribution of relevant documents [such as this Final Write-shop Report, Policy and Technical Briefs, and related materials].

* Develop a series of reader-friendly FACT SHEETS from the various sections of Chapters 6 and 7, to distribute at appropriate dryland-Africa fora and events. For example, see Annex 3.3.

3. Policy actions

Participants who worked on policy issues during the write-shop identified several areas in need of attention, among them:

- Strengthen policies on facilitating knowledge management and information sharing.
- Policy on standardization and certification of (export quality) dryland commodities, as well as legislation that supports market infrastructure and market information access at local level.
- An important preliminary action would be a rapid review and synthesis of existing policies, i.e.:
- Carry out a basic country-level policy assessment in each of the represented countries as a first step in closing the existing 'policy knowledge gap'?

"Evaluation of forestry policies [and related dryland development directives] for their continued relevance for sustainable development in the drylands and their capacities to engender proactive community participation in dryland forest management." Jama B. and Zeila A. 2005. Agroforestry in the drylands of Eastern Africa: a call to action. ICRAF Working Paper no. 1.

Although it was not clearly indicated for who such an assessment would be useful – no-one at the write-shop was aware of such a policy assessment. The Tegemeo Institute of Agricultural Policy and Development (affiliated to Egerton University) has the capacity and mandate to take on such an evaluation – and, at least for Kenya, would be an obvious starting point in developing a protocol and cost-effective approach.

4. Trees-in-drylands science

For those of us within the university/research community, develop possible graduate study initiatives to specifically tackle high-priority knowledge (management) gaps.

- Strengthen available datasets and databases on economic productivity and resilience of dryland species. An obvious starting point would be to overhaul and update the content of the ICRAF Agroforestree database to reflect existing knowledge (including documented indigenous knowledge) of dryland tree productivity.
- A worthy project for a small team (one or two graduate-level students in each country of the region) to identify 100+ or priority species. This would make an excellent poster presentation for the 2014 World Congress on Agroforestry.

Distribution channels for the other outputs will be:

ICRAF website, and other participating institutional websites [Kenya NDMA, World Vision-Uganda, CARE-Kenya, etc.] Other websites that have vested interest in such materials [IGADD-Reliefweb, FAO, CGIAR-CCAFS etc. [see Annex 2 Information Resources].

Chapter 11: References

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Annex 1: List of contributors to the consultative process

Below is a list of people who contributed to the consultative process, which resulted in the assessment of trees and resilience that is presented in this report. The first part comprises the list of those who also participated in the write-shop while the second part lists those who contributed in other ways.

Write-shop participants

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Annex 2: Sources of information

The participants of the workshop and the wider consultation shared with us a number of relevant information sources, which are listed below with a link to websites where these can be accessed.

Working Papers

Dewees, P.A. 2013.Bouncing back: forests, trees and resilient households. Working Paper prepared for the International Conference on Forests for Food Security and Nutrition, Rome, May 13 to 15, 2013.

Jama B and Zeila A. 2005.Agroforestry in the drylands of eastern Africa: a call to action. ICRAF Working Paper no. 1. Nairobi: World Agroforestry Centre, 29p.

Kapchanka, M., 2008.Wattle tree farming fizzling out of Kenya. *Kenya Chronicles:* a timeless journal of Kenya political, economic and social events, 22 July, 2008.

Watkins, K., and Alemayehu, W. 2012.Financing for a fairer, more prosperous Kenya: a review of the public spending challenges and options for selected arid and semi-arid counties. Washington, D.C.: Brookings Institution, 90p.

Reij, C.; Tappan, G.; Smale, M. 2009. Agroenvironmental transformation in the Sahel. IFPRI Discussion Paper 00914, IFPRI.

Books

Akinnifesi F K, Leakey RR B, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR. 2008. Indigenous fruit trees in the tropics: domestication, utilization and commercialization. Wallingford: CAB International, 438p

Coulter J. 1987.Market study for frankincense and myrrh from Somalia. Chatham: National Resources Institute, 37p

Farah A Y.1994. The milk of the *Boswellia* forest: frankincense production among the pastoral Somali. Uppsala: Uppsala University. Research Programme on Environmental Policy and Society (EPOS), Department of Social and Economic Geography, 146p

Funk C, Michaelsen J, Marshall M. 2011. Mapping recent decadal climate variations in Eastern Africa and the Sahel: remote sensing of drought - innovative monitoring approaches. London: Taylor and Francis, 270p

Hall JB, Walker HD 1991.*Balanites aegyptiaca:* a monograph. SchoolofAgriculture and Forest Sciences Publication no. 3. Bangor: University of Wales, 70p

NRC 2008 Lost crops of Africa: vol. III - Fruits. Development, security, and cooperation policy and global affairs. Washington, DC: National Academies Press, 380p

Rochelau, R., Weber, F. and Field-Juma, A. 1988.Agroforestry in dryland Africa. Nairobi: International Council for Research in Agroforestry (ICRAF), 311p

UN/ISDR, 2007. Drought risk reduction framework and practices: contributing to the implementation of the Hyogo framework for action. Geneva: United Nations secretariat of the International Strategy for Disaster Reduction (UN/ISDR), 98+vi p.Vrieling et al. (2013)

Briefs

Hesse, C. 2013 C:\Users\MaryNjenga\Downloads\17161IIED.pdf.IIED Policy Brief. London: IIED, 4p. Fitzgibbon C. and Crosskey, A.2013 Disaster risk reduction management in the drylands in the Horn of Africa. Brief 4. Nairobi: Technical Consortium for Building Resilience to Drought in the Horn of Africa, 21p.

Book chapters/sections

Barrett, C. B. (2005) Rural poverty dynamics: development policy implications. In: D. Colman and N. Vink (eds) Reshaping Agriculture's contributions to society. Oxford: Blackwell

Kapur, S. et al (eds). 2011.Sustainable land management learning from the past for the future. Heidelberg: Springer, p57-124

Kehlenbeck, K, Asaah, E, Jamnadass, R. 2013. Diversity of indigenous fruit trees and their contribution to nutrition and livelihoods in sub-Saharan Africa: examples from Kenya and Cameroon. In: Fanzo, J, Hunter, D, Borelli, T, Mattei, F (eds.) Diversifying food and diets: using agricultural biodiversity to improve nutrition and health. New York: EarthscanRoutledge, p257-269

Sahel Working Group. 2011. 4 pathways to resilience: an adapted approach to aid for the Sahel. In: Gubbels, P. 2011. Escaping the hunger cycle.

Shelton, H M 2005.**Forage tree legume perspectives.** In: Reynolds, S G and Frame, J. (eds). 2005. Grasslands: development opportunities perspectives. Science Publishers, p81-108.

Journal articles

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Annex 3: Other communication products

The consultative process resulted into a number of communication products which are listed below and are available on the project website: http://www.worldagroforestry.org/knowfor

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- Blog by Jan de Leeuw announcing the write-shop: Trees to increase resilience in East African drylands. http://blog.worldagroforestry.org/index.php/2013/07/08/trees-to-increase-resilience-in-east-african-drylands/

- Blog by Paul Stapleton on opening of the write-shop by ICRAF DG Tony Simons. http://blog.worldagroforestry.org/index.php/2013/07/15/invest-in-climate-resilient-futures-says-icraf-dg-tony-simons/

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