Tree-based production systems have enormous potential to reduce vulnerability and increase the resilience of households living in dryland regions of Sub-Saharan Africa. Trees are key providers of biomass, which is critical for many livelihood needs. Wood from trees is the leading source of energy in many dryland countries and is an important construction material. Foliage and pods from trees and shrubs are the most important source of feed for camels and goats, which are the dominant livestock species in the more arid parts of the drylands. Trees and shrubs offer enhanced sources of the organic matter needed to improve the structure and raise the fertility of soils used for agriculture. Many parts of trees provide different medicinal products for people. And fruits and vegetable foliage harvested from trees are important seasonal food sources for people living in drylands, and for sale.

The benefits from trees take on added value when one considers that they are relatively impervious to many of the shocks that affect other production systems, especially livestock keeping and agriculture. Trees, with their deep rooting systems, maintain their standing value and offer some production even in drought years. They are therefore a good buffer against climatic risk and are a critical element in a diversification strategy designed to maintain levels of consumption and income in good times and bad. In addition, their value can be tapped when it is most needed: wood from trees can be harvested throughout the year, and many annual tree products are harvested at times different from the times when annual crops are harvested.

Tree-Based Production Systems for Africa’s Drylands identifies some of the most promising investment opportunities at the level of tree-based systems, species (products), and well-defined management practices for accelerating rural economic growth in the drylands.

Frank Place, Dennis Garrity, Sid Mohan, and Paola Agostini
Tree-Based Production Systems for Africa’s Drylands
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Frank Place, Dennis Garrity, Sid Mohan, and Paola Agostini
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Contents

Foreword ix
Acknowledgments xi
About the Authors xiii
Executive Summary xv
Abbreviations xxii

Chapter 1 Conceptual Framework 1
Trees Reduce Exposure to Shocks 4
Trees Reduce Sensitivity to Shocks 5
Trees Help to Cope with Shocks 6
Summary 6

Chapter 2 Current Practice and Impacts of Tree-Based Production Systems in the Drylands of Africa 9
Production of Wood Products 11
Practices That Focus on Production of Non-Wood Tree Products—Products Consumed by People 14
Practices That Focus on Natural Resource Services—Regeneration and Planting 19
Tree Regeneration Practices That Generate Multiple Products and Services 21
Management of Existing Woodlands 29
Tree-Based Production Systems and Resilience 31

Chapter 3 Case Studies: Five Leading Tree-Based Production Systems in the Drylands 33
Farmer-Managed Natural Regeneration 34
Shea (Vitellaria paradoxa) 42
Cashew (Anacardium occidentale) 49
Mango 55
Timber and Pole Production 60
Note 66
# Tree-Based Production Systems for Africa’s Drylands

## Chapter 4 Identifying Priority Tree-Based Production Systems by Dryland Zone
- Arid Zone 69
- Semi-Arid Zone 70
- Dry Sub-Humid Zone 72
- Note 73

## Chapter 5 Policy Recommendations for Scaling Up Promising Tree-Based Production Systems
- Changing Attitudes/Mindsets toward the Integration of Trees in Agriculture 75
- Spreading Awareness and Knowledge of Improved or New Practices 76
- Improving Local Landscape Management—Especially Grazing Management, and Fire Control 77
- Increasing Tenure Security 77
- Strengthening Markets for Tree Products 78
- Expanding Financing of Tree-Based Production Systems 79
- Improving Tree Germplasm Supply 79

## References 81

### Box
1.1 Livelihoods, Natural Hazards, Vulnerability and Resilience 3

### Figures
2.1 Examples of Tree-Based Production Systems According to Aridity of Drylands 10
2.2 Production of Cashew and Mango in Africa, 2000 and 2012 16
3.1 Importance of Tree Revenue in West Africa 37
3.2 Mean Number of Young and Mature *Faidherbia* Per Field in the Sahel 41
3.3 Shea Value Chain in West Africa 44
3.4 Cashew Nut Production Trends in Major Producing Areas 51

### Maps
3.1 Distribution of Major Shea Tree Growing Areas in Africa 43
3.2 Primary Cashew Producing Countries in Africa 50
4.1 Dryland Zones in Sub-Saharan Africa 68
## Tables

3.1 Value of Harvested and Marketed Tree Products in Four Sahelian Countries  
   36
3.2 Private Economic Returns from FMNR  
   40
3.3 Cashew Nuts (with shell) Production Quantity, 2003 to 2011  
   49
3.4 Private Economic Returns from Mango Production in Kenya  
   58
3.5 Private Economic Returns from Pole and Timber Production in Kenya  
   65
Drylands—defined here to include arid, semi-arid, and dry sub-humid zones—are at the core of Africa’s development challenge. Drylands make up 43 percent of the region’s land surface, account for 75 percent of the area used for agriculture, and are home to 50 percent of the population, including a disproportionate share of the poor. Due to complex factors, the economic, social, political, and environmental vulnerability in Africa’s drylands is high and rising, jeopardizing the long-term livelihood prospects for hundreds of millions of people. Climate change, which is expected to increase the frequency and severity of extreme weather events, will exacerbate this challenge.

Most of the people living in the drylands depend on natural resource-based livelihood activities, such as herding and farming. The ability of these activities to provide stable and adequate incomes, however, has been eroding. Rapid population growth has put pressure on a deteriorating resource base and created conditions under which extreme weather events, unexpected spikes in global food and fuel prices, or other exogenous shocks can easily precipitate full-blown humanitarian crises and fuel violent social conflicts. Forced to address urgent short-term needs, many households have resorted to an array of unsustainable natural resource management practices, resulting in severe land degradation, water scarcity, and biodiversity loss.

African governments and the larger development community stand ready to tackle the challenges confronting dryland regions. But while political will is not lacking, important questions remain unanswered about how the task should be addressed. Do dryland environments contain sufficient resources to generate the food, employment, and income needed to support sustainable livelihoods for a fast-growing population? If not, can injections of external resources make up the deficit? Or is the carrying capacity of dryland environments so limited that out-migration should be encouraged as part of a comprehensive strategy to enhance resilience? And given the range of policy options, where should investments be focused, considering that there are many competing priorities?

To answer these questions, the World Bank teamed up with a large coalition of partners to prepare a study designed to contribute to the ongoing dialogue about measures to reduce the vulnerability and enhance the resilience of populations living in the drylands. Based on analysis of current and projected future
drivers of vulnerability and resilience, the study identifies promising interventions, quantifies their likely costs and benefits, and describes the policy trade-offs that will need to be addressed when drylands development strategies are devised.

Sustainably developing the drylands and conferring resilience to the people living on them will require addressing a complex web of economic, social, political, and environmental vulnerabilities in Africa’s drylands. Good adaptive responses have the potential to generate new and better opportunities for many people, cushion the losses for others, and smooth the transition for all. Implementation of these responses will require effective and visionary leadership at all levels from households to local organizations, national governments, and a coalition of development partners. This book, one of a series of books prepared in support of the main report, is intended to contribute to that effort.

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Executive Summary

Tree-based production systems (TBS) have enormous potential to reduce vulnerability and increase the resilience of households living in dryland regions of Sub-Saharan Africa. Trees are key providers of biomass, which is critical for many livelihood needs. Wood from trees is the leading source of energy in many dryland countries and is an important construction material. Foliage and pods from trees and shrubs are the most important source of feed for camels and goats, which are the dominant livestock species in the more arid parts of the drylands. Trees and shrubs offer enhanced sources of the organic matter needed to improve the structure and raise the fertility of soils used for agriculture. Many parts of trees provide different medicinal products for people. And fruits and vegetable foliage harvested from trees are important seasonal food sources for people living in drylands, and for sale.

The benefits from trees take on added value when one considers that they are relatively impervious to many of the shocks that affect other production systems, especially livestock keeping and agriculture. Trees, with their deep rooting systems, maintain their standing value and offer some production even in drought years. They are therefore a good buffer against climatic risk and are a critical element in a diversification strategy designed to maintain levels of consumption and income in good times and bad. In addition, their value can be tapped when it is most needed: wood from trees can be harvested throughout the year, and many annual tree products are harvested at times different from the times when annual crops are harvested.

Realizing the potential of tree-based systems will not be easy, however. Woody vegetation has degraded in many dryland areas, leaving inadequate biomass to sustain livelihoods. For this reason, as rural population growth continues to reduce woodland area and expand agricultural area, farms are becoming increasingly more important sources for tree products and services. The implications of this have not yet been given sufficient attention in dryland countries. This book identifies some of the most promising investment opportunities at the level of tree-based systems, species (products), and well-defined management practices for accelerating rural economic growth in the drylands.
Opportunities to Reduce Vulnerability and Increase Resilience

It is important to distinguish between systems that are based on broad regenerative practices and systems that are based on the purposeful planting and/or management of certain types of tree species. Regeneration leads to the emergence and use of a diversity of species which generate a range of products and services. In the drier areas of Sub-Saharan Africa, regeneration accounts for a large majority of the trees being managed by farmers.

Broad regenerative practices include farmer-managed natural regeneration (FMNR) of trees in croplands, and assisted natural regeneration (ANR) through exclosures/enclosures that rehabilitate rangelands or woodlands. These systems deploy a diverse range of species that are well-adapted to the local conditions and entail relatively low establishment costs. They are currently being expanded on large areas throughout the arid and semi-arid drylands, and they are now seen as foundational systems for application throughout these agroecosystems. It is important to emphasize that the regeneration of trees on farms occurs throughout the farm, including on crop fields. The result is a mosaic of trees integrated into other land uses such as cropping, pastures and fallows.

Purposeful planting and/or management of certain types of tree species that can produce economically valuable products and services is also important, particularly in dry sub-humid zones where rainfall is greater and the costs of planting trees are lower, the risk of losing trees to drought is less pronounced, and the productivity of trees is higher.

Farmer-Managed Natural Regeneration and Assisted Natural Regeneration

Farmer-managed natural regeneration on agricultural lands, and assisted natural regeneration on community lands, provide the most cost-effective way of achieving a widespread increase in numbers of valuable, adapted, and diverse trees. What these practices have in common is that in both cases, people (individual farmers or entire communities) actively influence natural biological regeneration processes to achieve patterns that better suit their needs. On agricultural lands, farmers identify naturally regenerating tree seedlings in their fields and manage them to provide various benefits (for direct products and for crops or livestock). On community lands, community groups may adopt the same practices, and they may also introduce grazing management systems at the community level that are designed to allow successful tree regeneration in targeted areas. Under both systems, protecting and weeding around young trees may be necessary to help them survive.

In recent years, FMNR has gained in popularity in many dryland areas in western, eastern and southern Africa. Because it requires very little or no cash investment, FMNR can expand rapidly through farmer-to-farmer and village-to-village
diffusion. The more than 5 million hectares of medium-to-high density tree cover newly regenerated on croplands in Niger provide a dramatic example of how quickly and how extensively the practice can spread (Reij, Tappan, and Smale 2009). And this may just be the tip of the iceberg. A recent study carried out in Niger, Mali, Burkina Faso and Senegal found that almost all farmers are actively regenerating trees (Place and Binam 2013).

The products and services derived from FMNR vary from location to location, depending on the tree species that are present in the area and that are valued by farmers. Throughout the Sahel, more than 100 woody species are being managed by farmers through natural regeneration. The value of these trees is high. They contribute products for human consumption (more than US$200 per household per year), feed for livestock during the late dry season, and they have positive effects on crop yields (accounting for roughly 15–25 percent of variation in millet and sorghum yields).

**Fuel Wood and Timber**

Trees are the leading source of energy in almost all rural areas of Africa, including drylands. Firewood and charcoal are widely used for cooking, bathing, laundering, and heating. In addition, in many countries the drylands are a major supplier of firewood and charcoal for urban areas. The estimated value of traded charcoal is currently in the billions of dollars, making charcoal one of the most valuable commodities traded in the region. Current fuel wood production comes mainly from off-farm sources, and the harvesting processes are frequently destructive to the environment. The governance of fuel wood production and marketing is poor, resulting in much uncertainty, extra-legal transactions costs, and poor incentives for long-term investment. There is huge scope for improved management of fuel wood from woodlands and the expansion of sourcing from farms through improved policy and regulatory frameworks.

Tree products (especially timber and poles) are also important as construction materials. The profitability of timber and pole production depends critically on the use of quality germplasm and adoption of careful management practices. Timber and pole production therefore almost always involve the purposeful planting of seedlings, which means they are best suited to areas in which rainfall is more abundant and more reliable (dry sub-humid areas of the drylands). Timber and pole production schemes in Sub-Saharan Africa have for the most part relied on exotic species, such as *Eucalyptus camaldulensis* or *Acacia mearnsii*. There are thriving examples of small outgrowers of woodlots for pulp and paper in southern Africa. In addition, many indigenous trees with high value have the potential to perform well, as long as sufficient attention is paid to germplasm selection and management. For example, *Melia volkensii* already supports a thriving high-quality furniture wood production industry in Kenya.
Non-Wood Tree Products

Trees and shrubs in the drylands produce many non-wood products that are extensively harvested for home consumption as well as for sale. These non-wood products include foods (fruits, nuts, and leaves); medicines; gums and resins; oils and fragrances; and fodder for livestock. The value of non-wood products varies considerably by region. Baobab contributes significantly to incomes in Senegal, shea in Burkina Faso, Mali and northern Ghana, gum arabic in the Sudan, and marula in southern Africa. Cashew is another important commodity for Africa, prominent in the savannah and sub-humid zones. Over 1.5 million farmers grow cashews, and production doubled between 2003 and 2011. Fruit production offers a potential growth area, as fruit consumption is growing at a rapid rate throughout the region as a result of urbanization and improved nutrition awareness. Kenya’s production of mango more than doubled in a recent six-year span. Production of other non-wood tree products can be expanded to meet growing export demand, such as cashew. For some of these non-wood products, the opportunities may lie more with value addition, rather than with production. For example, there are hundreds of millions of shea trees across Africa harvested to meet the moderate growth in demand, but greater investments farther up the value chain may be more profitable. In the cases of shea and cashew, only a small fraction of the exported product is processed domestically.

Tree-Based Systems for Natural Resource Management

Trees provide many environmental services, including carbon sequestration, watershed protection, and soil health enrichment. These services can be generated either through FMNR or by purposeful tree planting. All trees sequester carbon at a relatively stable proportion of 0.5 of the woody biomass dry weight. Tree growth is slower as aridity increases, and the annual aboveground carbon sequestration from a typical regenerated field may be around 1 ton per hectare in the semi-arid regions with an additional third of that below ground. In addition to the positive effects that FMNR has on a range of services, in the dry sub-humid zone and selected low lying areas of the semi-arid zone, hundreds of thousands of farmers have planted nitrogen-fixing trees to boost cereal yields and to reduce the variability in yields due to climate variation. These TBS supply a large amount of nitrogen very cheaply and also benefit soils in many other ways such as soil carbon build up and improved soil physical structure.

Contribution of Tree-Based Production Systems to Economic Benefits and Resilience

In-depth economic analyses were carried out for five TBS case studies: FMNR, timber and poles, shea, cashew, and mango. The results show that increased investment in FMNR and in the production of timber and poles, mango and cashew is profitable under most assumptions concerning prices, costs and
discount rates. Some investments begin to generate benefits in a few years’ time, while others take longer (for example, timber), but the payoffs are significant enough to provide positive returns on investment. The case of shea is different in that there is a huge number of existing trees. All trees can contribute positively to some dimensions of resilience in that their deep root systems make them hearty against variations in climate, meaning that at a minimum, their standing volume is normally non-decreasing over time. Investing in FMNR is likely to bring forth the most resilience in the drylands, as it will generate the highest number of trees of species that are suitable to the conditions. Trees reduce sensitivity to risk through micro-climate effects of reducing temperatures, wind speeds, and other positive effects. When practiced at scale, as is observed in some landscapes of the Sahel, there is potential for TBS to reduce exposure to the risk of dust storms.

**Challenges**

Five types of challenges threaten the successful diffusion of TBS: (i) technical, (ii) institutional, (iii) legal, (iv) economic, and (v) cultural.

*Technical*: The main technical challenge to the wider planting of trees relates to the availability of water for tree nurseries in the dry season, and for early stage watering of trees in the more arid reaches of the drylands. For that reason, planted trees are recommended mainly for the dry sub-humid zone, and only for high-value trees in the semi-arid zone. Farmer-managed natural regeneration on farmlands and assisted natural regeneration in community lands are much more suitable in the more arid zones and are therefore proposed as foundational TBS for the arid and semi-arid areas.

*Institutional*: During their early stages, trees are vulnerable to heavy livestock browsing and to fire. Local institutions therefore need to be designed in ways that ensure the protection of trees.

*Legal*: Forest regulations in many dryland countries discourage farmers from effectively managing indigenous species on their farms, for example by requiring farmers to pay for licenses to cut trees on their own land. Where these policies and regulations have been revised in recent years, farmers have responded with an explosion of tree regeneration on their lands.

*Economic*: A major challenge constraining the expansion of TBS in drylands is the fact that markets for many tree products are as yet poorly developed.

*Cultural*: Although research has demonstrated the benefits of intercropping trees and crops, and farmers have been practicing this for generations in some dryland areas, extension messages still emphasize conventional agricultural methods whereby crops are to be grown in “clean” fields.

**Policy Recommendations**

Tree-based systems have great potential to reduce vulnerability and increase resilience of households living in the dryland regions of Sub-Saharan Africa. This
potential is not always appreciated, however, so work remains to be done to change the mindsets of policy makers, development professionals, and even technical specialists such as researchers and extension agents. For many, mixing trees with crops is considered unconventional and to be avoided, yet a growing body of evidence suggests that successfully integrating trees into farming and livestock keeping activities can be extremely profitable, provided the appropriate species and management practices are used.

The key areas for policy attention are:

1. Encourage change in the attitudes and mindsets of development professionals towards the pro-active integration of trees in agriculture
2. Spread awareness and knowledge of the range of improved or new TBS practices
3. Improve local landscape management to enhance the role of TBS—especially focusing on grazing management systems and fire management
4. Expand the supply of quality tree germplasm
5. Increase tenure security for land and trees, especially for women
6. Strengthen markets and value chains for tree products
7. Expand investment financing for scaling-up the range of TBS in the drylands

Investments in these areas do not need to be borne primarily by the public sector. Helping to strengthen markets for tree products through engagement with the private sector has been shown to attract and leverage additional finance and awareness generation for TBS from the private sector in some countries.
Abbreviations

ACi     African Cashew initiative
ANR    assisted natural regeneration
AU     African Union
CAMPFIRE Community Areas Management Programme for Indigenous Resources
CBI    cocoa butter improver
CNSL   Cashew Nut Shell Liquid
FAO    United Nations Food and Agriculture Organization
FMNR   farmer-managed natural regeneration
FTTs   fertilizer tree technologies
ICRAF  World Agroforestry Centre
NGO    nongovernmental organization
NWTPs  non-wood tree products
TBS    tree-based production systems
UNCTAD United Nations Conference on Trade and Development
WHO    World Health Organization
Interest in African drylands development has increased in recent years. This has been driven mainly by recognition that while drylands have been the target of significant humanitarian aid over the last three decades, comparatively little effort has been put into development that would increase people’s resilience and reduce their dependency on aid. The reawakened interest has translated into support for livestock and crop-based development pathways, and efforts to foster resilient livelihoods revolving around these agricultural commodities. Such efforts, however, will be of limited impact without attention to a broader systems approach building on the synergies that trees provide in these systems based on a crop-tree-livestock perspective.

In spite of being exposed to the relatively unfavorable dryland climate, dryland people and communities have acquired through the millennia considerable resilience to these conditions, which enables both land and human well-being to 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 the land and the people.

This book focuses on tree-based production systems (TBS) and reviews the rapidly evolving evidence that these systems are of critical importance, and that there are widespread successes in their deployment across large areas by smallholder rural populations in the drylands.

The term “Tree-Based Systems” is defined in the context of this book as agricultural (cropping) systems, forest/woodland/shrubland systems or pastoral (rangeland) systems in which woody perennials play a significant economic role. Within each of these classes of land use, a wide range of different tree species play an economically and/or ecologically important role. Likewise, a considerable range of tree management practices are used in these three systems. This book examines a subset of this variation. It identifies and analyzes some of the most promising investment opportunities at the level of systems, species (products), and well-defined management practices for accelerating rural
economic growth in the drylands and enhancing ecological functions at the farm, village and landscape scales.

In the agricultural domain, production of the most important dryland crops is already typically associated with dispersed trees in the farm fields. This form of land use is referred to as agroforestry parklands in the Sahelian context (Boffa 1999). Variants of the parkland system are also common in the East and Southern Africa drylands (Dewees 1996).

Often, the trees in these systems directly provide an important product such as wood, gum, oil or fruit. In other cases, they provide an input into the production of major products such as foliage used as fodder for meat and milk, tree nectar for honey, and tree leaves as biofertilizers for improved soil health and crop production. A considerable number of well-recognized species and products are associated with the African drylands. These include the baobab tree (*Adansonia digitata*), which provides nutritious fruits and leaves; the shea tree (*Vitellaria paradoxa*) that provides butter used in cooking and in chocolate and cosmetics; Gum Arabic (*Acacia senegalensis*) that provides a gum used in many food items; and *Faidherbia albida* which enriches soils and provides valuable pods and foliage for fodder. The environmental services derived from trees on farm-lands provide another significant stream of benefits, such as soil and water conservation, and a more favorable microclimate for crops to withstand wind and drought stress.

Regeneration or restoration effects realized at a landscape scale are a major outcome of TBS investments. These cover a wide range of practices that enrich the quality of the land resource, and they provide additional environmental benefits such as watershed protection and enhanced biodiversity. The natural regeneration of trees may be applied across the range of land use types such as forests, woodlands, rangelands, and farm lands. Restoration at scale has been achieved through the efforts of a large number of rural residents, such as the example of the re-greening of the parklands in Niger and Mali, and the large-scale watershed rehabilitation efforts ongoing in Ethiopia.

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 (DFID 2000). Livelihoods in the drylands are affected by a number of natural hazards. Repetitive drought is the most prominent natural hazard; others include floods, and animal and human diseases, often triggered or intensified by these. Other factors, such weak institutions and inadequate policies, are human-induced hazards that exacerbate the impacts of these natural hazards. Conflict is another shock that is not uncommon in dryland areas; witness the prolonged conflict in Somalia and insecurity in the northern regions of Mali and Niger. Drylands, as in other areas, are also not immune to economic risks, which are felt primarily in terms of shortages of foods or surging prices for foods and inputs.
Box 1.1 Livelihoods, Natural Hazards, Vulnerability and Resilience

Poverty indicators that focus on income do not completely capture human well-being. This is because important factors beyond financial income determine the ability of people to make a living. The livelihood approach (DFID 2000) groups these factors under five types of assets that underpin livelihoods. First is the **human capital** representing the skills, knowledge, ability to generate labor, and good health that together enable people to pursue different livelihood strategies and achieve their livelihood objectives. Second is the **social capital** such as networks and relationships based on trust, reciprocity and exchanges. Third is 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 peoples’ livelihood. Fifth is the **financial capital** denoting the financial resources that people use to achieve their livelihood such as available stocks of cash, bank deposits, liquid assets such as livestock or trees, 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 application because it brings together these various components that contribute to human well-being. Trees contribute to both the enrichment of household assets as well as to building the resilience of that asset base to shocks. The main direct effect of TBS is through the building of productive natural capital. Trees are a component of natural capital, but they also strengthen other assets such as soils, livestock and farm-level infrastructure. Through this enrichment, other assets can be built up as well.

The effect of TBS on livestock exemplifies the asset enriching benefits from TBS in the drylands. In agropastoral communities, there is normally a dearth of livestock fodder resources at the end of the dry season, which is a serious constraint to sustaining and building up livestock assets. The presence of tree resources on the croplands increases the fodder supply in the late dry season in normal years, as some trees can be pruned at that time of year for enhancing a supply of high-quality forage. During prolonged drought periods the supply of other fodder sources (crop stover and pasture grass) is reduced, and tree-based fodder resources become even more important.

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 (see box 1.1).

**Vulnerability** is an undesirable condition referring to the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effect of the hazard. Vulnerability is often the result of extreme poverty, especially where poor people have limited options to sustain their livelihoods, and exposure to hazards that compromise their primary livelihood.
A typical example from the drylands would be where a long-term drought has begun to push food prices up and affects the condition of pastoralists’ or agropastoralists’ livestock or causes death of the animals. When they find themselves in a position where it is difficult to sell excess stock to buy food and guard against future hunger, or livestock prices collapse because many are disposing of their herds simultaneously, they find themselves in a massively deteriorating situation.

*Resilience* is a desirable condition, often regarded simply as the converse of vulnerability, where people have the means to protect themselves from hazards. Complete protection from exposure to drought, flood and other eco-physical factors is impossible (it either rains or it does not).

The concept of resilience has various connotations, which revolve around how a system responds to disturbances.

*Instant responses* include the capacity of a system to absorb a shock and to recover and regain pre-disturbance conditions. Immediate responses suffice during smaller disturbances, which people are familiar with and for which they have developed mechanisms to cope. However, instant responses may not suffice when vulnerability is increased, or during larger and unprecedented hazards. Adaptation and transformative resilience are delayed responses because they require time for social change.

Resilience can be analyzed from another perspective as well: managing exposure to shocks, managing sensitivity to shocks, and coping with shocks. Typical shocks such as drought, pest outbreaks, or economic crises are exogenous to households and even communities/regions and there is often little that people can do to prevent them from occurring. Thus, exposure to risk is highly correlated among households living in the same place. Sensitivity is measured by the effect that such shocks have on a household or community, and preventative strategies that are undertaken by those agents can lead to different levels of sensitivity to risk. Coping strategies are those actions taken after the effect of a shock is felt by an individual, household or community. All agents have coping strategies but they differ considerably in terms of their effectiveness in addressing the shock and in terms of the long-term effects they have on household well-being.

**Trees Reduce Exposure to Shocks**

In the dryland regions of Africa, there is relatively little that individual households can do to reduce their exposure to shocks, short of moving away. If a household is located in a place that is affected by a weather shock or by a price shock, the household will be exposed. However, many households acting together (engaging in collective action) can sometimes achieve landscape-level effects that do in fact reduce exposure. An example of this is the reduced incidence of weather-induced dust storms in south central Niger due to the widespread regeneration of agricultural landscapes with a contiguous tree cover.
Farmers testify that in the absence of tree populations on their fields they were often forced to replant multiple times. With regenerated tree populations, wind speeds are dramatically reduced and this is no longer necessary.

At the macro level, recent modeling studies have demonstrated that tree-covered landscapes, which tend to have higher evapotranspiration rates, have a tendency to positively influence rainfall regimes in landscapes downwind from them (Ent et al. 2010), thus reducing the exposure to drought.

**Trees Reduce Sensitivity to Shocks**

Trees can play an important role in reducing household sensitivity to shocks. Although trees are not impervious to climate change, their deep rooting systems, which access deeper sources of water, make them less vulnerable to seasonal rainfall reductions. This robustness then enables trees to play particularly important roles in reducing sensitivity to at least three important types of shocks: weather-related shocks, climate-related shocks and health-related shocks.

*Reduced weather-related shock sensitivity.* The dominant weather-related shock is droughts that are unusually severe, frequent or prolonged. Trees in crop fields directly and significantly ameliorate the severity of drought effects on annual crop performance by modifying the microclimate. Crops in the vicinity of trees experience a more favorable microclimate with significantly higher humidity in the crop canopy causing a lower vapor pressure deficit, and trees also slightly lower solar radiation stress. Trees also increase the infiltration and storage of rainfall in the soil by reducing surface runoff. The additional biomass that they provide increases soil organic matter, which enhances both soil moisture storage and nutrient availability to the crops. Moreover, there are circumstances under which some trees effectively transfer water from deeper depths up to near the soil surface through their root systems and make such water available to nearby crops ("hydraulic lift"—Bayala et al. 2014). These phenomena reduce the rate of onset of crop water stress, enabling crops to more successfully withstand periods of drought during the growing season.

*Reduced climate-related shock sensitivity.* Global temperatures are significantly increasing as a result of climate change. Average temperatures in the Sahel have increased by about one degree Celsius during the past 40 years (UNEP 2011). Periods of extreme day-time temperatures are also more frequent and severe. Most annual crops experience a reduction in their yield potential as a result of higher temperatures due to two processes: they have higher respiration rates which burn up more of their energy, making less available for grain filling; and a shortening of the crop maturity period which reduces the size and weight of the grain.

Trees in crop fields significantly reduce temperatures in the crop canopy and soil, thus reducing the crop exposure to high temperature shock, particularly in mid-day. Across the growing season the aggregate effect is to reduce the shock of a shortened crop maturity period, thus enabling it to photosynthesize longer and
increase grain filling and yield. The sum of these effects of reduced shock sensitivity is observed in more stable crop yields in drought years in fields with tree populations than in fields without them. Surveys in Niger comparing the crop performance in drought years between villages and households with and without the practice of farmer-managed natural regeneration of trees have provided evidence on this (Reij, Tappan, and Smale 2009). The data are consistent with farmer observations that higher tree populations reduce drought effects.

**Reduced health-shock sensitivity.** TBS may reduce sensitivity to health shocks during seasonal or prolonged drought-induced hunger periods. Fruit and vegetable foods from trees are obtained from the farm or from the forest during these periods (Place and Binam 2013). These products also assist in sustaining and improving the nutritional levels of people. For example, the fruits and leaves of baobab are highly nutritious in vitamins A and C which are lacking in staple foods (Orwa et al. 2009) or unavailable from other sources during the dry season.

**Trees Help to Cope with Shocks**

A diverse portfolio of trees can enhance a household’s ability to cope with stresses, because the products mature at different times during the year. For example, the mango fruit ripens and is widely available at the end of the dry season, just as the rains are about to begin in the West African Sahel. Leaves from several trees are available as sources of vegetable protein throughout the year for human or livestock nutrition (for example, baobab, moringa, and others).

Trees are assets that can be cut and sold for cash or exchanged for goods in times of need. In the Maradi and Zinder Regions of Niger, where 1.2 million households now sustain medium-to-high densities of tree populations on their farms, tree branches are cut on a continuous cycle for household fuelwood supplies and for sale, and some mature trees are cut down and sold in local wood markets for poles and construction materials. Export markets are active in shipping wood south to Nigeria. During prolonged drought periods, these tree assets may be gradually liquidated to supply the household with cash for food purchases. This process was observed to be an important source of coping capacity for households during recent droughts (Reij, Tappan, and Smale 2009).

**Summary**

Trees are important to the livelihoods of dryland households and can contribute in many ways to resilience. Income from wood and non-wood tree products can make a significant contribution to rural households’ budgets and their food security. The services that trees provide for crop and livestock systems are in many cases even more important and valued than the direct products. Chapters 2 and 3 provide rich examples of specific tree-based practices and species that are generating such impacts.
Chapter 4 proposes key recommendations for scaling-up tree-based investments and chapter 5 addresses the challenges and proposed steps to overcome them. It will be clear from these sections that building resilience and improving livelihoods requires an integrated approach.
Many tree-based production systems (TBS) not only are profitable, but they also reduce vulnerability and increase resilience of households living in African dryland environments. The benefits of TBS manifest themselves through major products and services such as:

- Increased livestock production (intensive, mobile pastoralism, transhumance)
- Increased crop production (sorghum-based systems, millet-based systems, maize-based systems, wheat-based systems, teff-based systems, groundnuts-based systems)
- Fuel wood and other energy production
- Timber, poles and other wood production
- Production of non-wood tree products (fruits, oils, medicine, textiles)
- Environmental protection (soil fertility, erosion control, wind breaks, community conservancies)

In a humid environment, each of these benefits would be pursued through purposeful tree planting by farmers. Indeed, one observes such practices widely in the humid highlands of Kenya, for example. However, the drylands create challenges to the planting of trees, the main one being lack of water for nurseries during the dry season and for supplementary watering during the early phases of growth. Thus, natural regeneration becomes the overwhelmingly important means of establishing trees in the drylands, especially in the more arid areas. Farmers regenerate trees throughout their farms, even within crop fields, in order to obtain the variety of benefits listed above. Because regeneration practices are so important in the drylands, we have given them special attention in the following sections. Thus, our typology of TBS will include some that are overlapping...
with others in order to cover a range of products, services and regeneration practices. This also ensures that the discussion is relevant to the different dryland zones because several of the tree products are suitable only for the dry sub-humid zone. The relevance of sample TBS for different aridity zones is depicted in figure 2.1.

Specific practices around which investments have been made and can be formulated are:

1. Practices that focus on production of wood products—regeneration and planting
   a. Timber/poles (e.g., through woodlots or boundary planting)
   b. Firewood/energy
2. Practices that focus on production of non-wood tree products—through natural regeneration and tree planting
   a. Shea, Gum arabic, cashew, African locust bean, various fruits, honey
   b. Tree and shrub fodders
3. Practices that focus on natural resource services—regeneration and planting
   a. Soil fertility and erosion control (rotating or intercropping trees and crops)
   b. Windbreaks and shelterbelts
4. Tree regeneration practices that generate multiple products and services
   a. Farmer-managed natural regeneration of trees
   b. Exclosures for degraded land and rangelands
   c. Management of existing woodlands
   d. Community conservancies

Figure 2.1  Examples of Tree-Based Production Systems According to Aridity of Drylands

![Diagram showing examples of tree-based production systems]

Note: FMNR = farmer-managed natural regeneration; TBS = tree-based production systems.
These are not neat, mutually exclusive classes. The regeneration practices (4) always create multiple benefits, which are noted in (1) to (3). Furthermore, specific practices and species can yield multiple benefits. For example, many trees are multipurpose, and often those which can enrich soils are also useful as fodder. Similarly, the production of trees for soil improvement or trees for poles yields additional wood that can be used as fuelwood.

The remainder of the chapter is structured according to the 10 practices listed above (1a through 4b). In discussing these practices, links are made to the key product and service benefits.

Production of Wood Products

Timber/Poles (for example through Woodlots or Boundary Planting)

Timber and pole production practices will normally be in the form of plantations of an industrial scale or at a smallholder level, referred to as woodlots. Timber and pole production can also occur in more integrated ways as in rows mixed with crops (for example the poplar-cereal intercrops in dryland India) or through boundary planting (for example the widespread use of Grevillea on boundaries in central Kenya). According to United Nations Food and Agriculture Organization (FAO) figures, about half of plantations in Southern Africa are in South Africa, while almost all plantations in East Africa are in Ethiopia and Sudan (FAO 2005). The aggregate area of plantations for most of Africa is low, ranging from 1,000 to 2,000 square kilometers per country (Chamshama et al. 2010).

_Eucalyptus sp._ and _Acacia sp._ are the most common trees planted in the dry parts of Africa for timber, firewood, tanbark and gums. Other species planted in dry areas include _Azadirachta indica, Melia volkensii, Albizia lebbeck, Senna siamea, Dalbergia melanoxylon_ and _Azadirachta indica_ (Neem). Growth rates of dryland timber trees vary greatly, between 1 and 30 m³/ha/yr. Depending on the range of agroecologies of a country, wood production in drylands may compete against production in more humid areas. For example, Green Resources Ltd, a producer of timber in Africa, has selected sub-humid to humid locations for its plantations in Tanzania, Mozambique and Uganda. Competitiveness and profitability of dryland timber production will be greater, _inter alia_, where dryland zones are situated close to processing or consumption areas or in countries where there are few non-dryland alternatives (for example, Namibia, Botswana, the Sahelian countries).

A concerted effort has been made in Ethiopia to expand the planting of woodlots either through groups or individuals. This is perhaps most visible in the region of Tigray (Gebremehdin, Pender, and Tesfaye 2000; Jagger, Pender, and Gebremedhin 2003). Evaluations of the economic potential of woodlots indicate that at current levels of land use and prices they can out-compete annual food crops on a per hectare basis, even accounting for the longer period to benefits. However, a study by Jagger, Pender, and Gebremedhin (2003)
showed that even the more mature community woodlots were yet to be fully harvested. In Zimbabwe and South Africa, where drylands prevail, there is an active plantation and woodlot sector. Although there are several industrial-scale operations, there are equally a number of outgrower schemes involving many smallholder farmers or cooperatives (Desmond and Race 2003).

Firewood/Energy
Fuelwood, including firewood and charcoal, remains the most important source of primary energy consumption in Africa and dominates among cooking energy sources in Africa. Over 90 percent of the overall population of 852 million and virtually 100 percent of the 535 million rural residents rely on fuelwood for energy (World Bank 2011). With urbanization, however, the growth rate of charcoal is estimated to be three times as high as that of firewood. In addition to use by households, some industries such as tobacco, tea, and brickmaking are major users of fuelwood. Charcoal remains the most important cooking fuel in about 20 of the 30 major cities in Sub-Saharan Africa (Malimbwi et al. 2010). Although hard evidence is not available for all countries, it is estimated that charcoal is the highest value traded commodity in Africa. The consumption of charcoal in Africa is estimated by FAO to have been 20.5 million tons in 2003 and 23.6 million tons in 2007 (cited in Vos and Vis 2010). Charcoal in Kenya represented an annual business of about KSh17 billion (US$213 million) in 2002, which was about 53 percent of the 1998 bill for imported oil. By 2013, the retail value of charcoal used in Kenya was estimated at US$920 million (Owen 2013). By 2030, the African market is predicted to exceed US$12 billion, employing 12 million people (World Bank 2011). The value of firewood used is also huge. The per capita daily consumption among the rural population is between 1 and 3 kilograms.

Given the lack of “official” data, estimates of the importance of different source locations for charcoal are inferred from specific studies. One study in Kenya found that whereas plantation forest/trees were a major source of wood for charcoal supplied to Kisumu, it was rangeland and natural forest/woodland clearings that were the main sources of charcoal supplied to Nairobi and Mombasa (cited by Malimbwi et al. 2010). The drylands often provide the bulk of fuelwood, because in the higher agricultural potential areas there is little non-farm land, and higher value enterprises are grown on farms. Another study from Kenya (Mutimba and Barasa 2005) estimates that 38 percent of charcoal is sourced from trees on farms. Most of the charcoal in Tanzania and Mozambique is produced from land under village control, while in Burkina Faso, Mali and Niger communal and state forests supply fuelwood to major cities. Namibia has a well-developed private sector charcoal production sector, including a National Association of Charcoal Producers.

In terms of implications for investments in charcoal, there may be production opportunities on farms as well as in woodlands to meet the growing demand.
Investments can be in different forms including in wood production—for example, in securing rights in woodlands or for purchasing seedlings for private farmers. Investments in charcoal-making methods/kilns can also be profitable by improving the efficiency of energy conversion. At the consumer end, there again is the potential for investment in improved stoves, for which a number of locally produced models have come onto the market.

While virtually 100 percent of charcoal is sold, thus representing a large market potential, firewood is much more a subsistence commodity in that much is consumed by the collector. Although firewood is considered to be scarce in some locations, it is not often the main purpose behind tree planting by smallholder farmers. Rather it is a byproduct from trees planted for poles or timber or other purposes. Therefore, compared to charcoal the potential for investment in firewood-related production is relatively low.

One of the challenges for firewood or charcoal production in the drylands is the slow growth of the trees. Regrowth times for charcoal supplies range from 15 to 30 years in the drylands with no management. Management—principally the thinning of coppices—can help reduce the time period as well as improve the quality of the charcoal. However, the economics of hiring labor to do this may not make sense where charcoal prices are relatively high.

Another barrier is policy, whereby the legality of various charcoal-making activities is uncertain at best. Sudan is an exception. The government recognizes charcoal as an important commodity and has taken specific actions to improve the sustainable supply of wood and to bring charcoal producers more formally into the system. A similar approach has been taken in Chad where lower taxation on fuelwood from sustainable sources has been implemented with many positive impacts on the organization of fuelwood production (Klas, Besrik, and Waqar 2011). Moreover, the revenues and taxes are partially plowed back into the sector. Contrast this with Kenya, where despite formal policy change, charcoal production and marketing is still clandestine and subject to all sorts of illicit payments to the police, who do nothing to bolster the sector (Owen 2013).

The potential for biomass to produce electricity in Africa has hardly begun to be exploited. Sri Lanka has developed a renewable energy system for the production of electrical power from the cultivation of nitrogen-fixing gliricidia trees by smallholder contract farmers. The trees are established on their farms and heavily pruned (removal of branches) every eight months. The wood is used as feedstock for power generation by either steam turbine power plants or smaller gasification units (pyrolysis process). The interesting aspect of these integrated systems is that the smallholders sell the wood for power, generating a cash income, while they retain the leaf foliage for a high-quality livestock feed source, and for fertilizing their soils for their food crops. Such a system is likely to be most promising in dry sub-humid zones due to the ability to plant dual purpose trees in desirable patterns and densities.
Non-Wood Energy from Trees

Trees and shrubs can also provide inputs to liquid fuel production through wood conversion or through processing of oils. It is the oils that have so far attracted some investments in Africa. Some oil-bearing trees such as jatropha have particularly interested governments and investors as they have been known to grow in dry areas where there is potentially more available land.

Although there was much hype about jatropha, agronomic and financial analyses conducted on the first five years of planting in Tanzania, Zimbabwe and Kenya show that yields are very low, well under a mean of 1 kilogram per tree against projections of more than five times that amount (Iiyama et al. 2013). At such low levels, there are no profits. There are several other trees such as Croton megalocarpus that also have good traits insofar as oil production is concerned. But much more agronomic research is required for all such species, even before the challenges of marketing the products are given attention.

Practices That Focus on Production of Non-Wood Tree Products—Products Consumed by People

In the category of non-wood or non-timber tree products, a large number of specific products are grown and/or harvested in the drylands for home consumption or sale. Products include fruits, nuts, oils, gums, resins, edible leaves, and medicines from various tree parts. This group also includes honey, whose production is dependent on trees. In some cases, for example, shea products derived from the trees may contribute more towards household income than any other single agricultural product. A single species can produce several important products such as leaves or fruits for human consumption, and pods or leaves for livestock feed and human or livestock medicines.

Non-wood tree products (NWTPs) are used in virtually all dryland communities of Africa. But the range of species, the investment in their management and processing, and their importance to livelihoods differ. In the Nuba Mountains, Sudan, El-Tahir and Gebauer (2004) found that respondents named 20 different tree species used for food. Among them, 19 were fruit tree species, and 5 species had leaves which were partly or exclusively used as vegetables. For 30 percent of the respondents, selling collected tree products was the most important income source. Non-wood commodities have a range of specific harvesting periods during the year, enabling a productive distribution of labor. From the point of view of a portfolio, a given landscape of food-bearing trees will be able to provide food products across many months of the year.

Fruits

Fruits and nuts are very important in all dryland zones. Due to economic and human population growth and increasing urbanization, fruit markets in Sub-Saharan Africa are predicted to grow substantially, for example, by 5.7 percent per year in Kenya (calculation of International Council for Research in
Agroforestry [ICRAF] based on Ruel, Minot, and Smith 2005). Taking FAO’s figures of current consumption on the continent, this can be equated very approximately to an annual increase in consumption of more than 10 million metric tons over the next decade, which equates to around US$2 billion in increased farm gate value at current prices. However, current fruit consumption in Africa is still very low. As an example, average daily consumption is only 36 grams per person (Ruel, Minot, and Smith 2005) in East Africa, which is far below the recommended daily amount of 400 grams of fruits and vegetables per person (WHO 2004). A case study of 104 households in the drylands of Mwingi District, Eastern Kenya, showed that as little as 28 grams of fruit was consumed per person per day, 19 grams from indigenous fruits and 9 grams from exotic ones (Kehlenbeck, Asaah, and Jamnadass 2013) although there are many species in the region that fruit at various times of the year.

In the semi-arid and dry sub-humid areas of Africa, the exotic mango tree is extremely important, having been successfully naturalized throughout the continent. Figures from Kenya suggest a very large level of production. According to FAO, exports of mangoes totaled US$14 million in 2005. At the same time, it was estimated that only 1 percent of all mangoes produced were exported, with about 50 percent of domestic production being sold in national markets and 50 percent consumed on farm (FAO 2005).

The largest group of fruit trees used in the drylands consists of indigenous trees such as baobab, shea, African Locust Bean (nere), uapaca, and ziziphus. Shea and uapaca products are used to supply major agribusinesses in cocoa and wine manufacturing, respectively. The shea tree (Vitellaria paradoxa) grows extensively in the agroforestry parklands of semi-arid Africa in a 5,000 kilometers long by 500 kilometers wide zone stretching from Guinea to Sudan, and is found in 18 countries from Senegal to Kenya. Estimates on the exact size of the total shea tree area are generally around 3 million square kilometers around Africa. There are hundreds of millions of shea trees in Africa, partly because they can live to be more than 200 years old. A recent study in the Sahel found that 70 percent of households had shea trees on their farms in Burkina Faso and Mali (in Segou and Mopti regions) (Place and Binam 2013). Total production potential reaches over 2.5 million metric tons of kernels. There is a large domestic consumption of shea (including household auto-consumption, local sale of shea kernel to processors, and shea butter to consumers) as well as thriving and growing export markets. Well over half of shea butter produced in Africa is consumed at the household level or sold in local markets. (See chapter 3 for a more in-depth case study on shea.)

Cashew is a major cash crop in Africa, distributed from the coastal lowlands through to dry sub-humid zones. The cashew tree’s tolerance of drought conditions and its ability to grow on poor soils and to be intercropped with food crops make it an ideal species for small farmers. About 1.5 million farmers grow cashew, earning Africa well over US$414 million in annual exports. The main cashew producing countries by tonnage are Nigeria, Côte d’Ivoire, Benin,
Mozambique, and Tanzania. In 2011, according to FAO estimates, Sub-Saharan Africa produced over 1.8 million tons of cashew nuts (with shell), a near 100 percent increase from the 2003 production of 934,000 tons. An increasing demand for cashew nuts on the world market has seen it grow six-fold since the 1980s, from 0.5 million tons to over 3 million tons in 2006 and 2007 (Grobe-Rüschkamp and Seelige 2010).

Within Africa, there is a positive trend in cashew production from West Africa, which since the 1990s increased its share of exports from 8 to 18 percent. Since the mid-1990s, Nigeria has emerged as the leading cashew producer in Africa. The production of cashew nuts (with shell) in Nigeria has increased almost 60 percent, from 524,000 tons in 2003 to 835,000 tons in 2011, from about 300,000 producers. Conversely, the East African countries (Kenya, Mozambique and Tanzania) saw their shares decline further from 7.5 percent in 1990/91 to 5 percent in 2007/08.

Numerous factors are in favor of increased cashew cultivation in Sub-Saharan Africa. There is a long history of cashew production in many countries, and production is growing every year. Although processing capacity is currently limited, the prospect of increased manual and automated processing is economically attractive. (See chapter 3 for a more in-depth case study on cashew.)

Data on production trends are not easy to find and FAO tracks only a few commodities relevant to the drylands. However, data on cashew and mango show significant growth, of between 100 and 200 percent, between 2000 and 2012 (see figure 2.2).

*Uapaca kirkiana* is a fruit tree found in the miombo ecosystem in Southern Africa. It is not commercially planted, but a large number of people harvest fruits and market them for domestic markets. A study in Zimbabwe showed that households in several regions benefitted from between US$10 and US$40

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**Figure 2.2 Production of Cashew and Mango in Africa, 2000 and 2012**

*in tons*

![Figure 2.2 Production of Cashew and Mango in Africa, 2000 and 2012](image)
annually per household from sales of its fruit (Mithoefer and Waibel 2003). *Adansonia digitata* (Baobab) is an African tree indigenous to the arid and semi-arid savannah of West, East, and Southern Africa. Baobab provides highly nutritious leaves and fruit for local consumption, and other products which serve a multiplicity of uses. Compared on weight basis with other dried fruits, baobab fruit pulp offers more than twice the dietary fiber of apple, more than twice the calcium of milk, more than twice the iron of spinach, and significantly more potassium and magnesium than banana (Phytotrade/Afriplex 2009).

*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 of these products are consumed at household level and also traded by dryland communities.

### Gums, Oils and Resins

Gums and resins are important sources of income for the rural poor in the drylands as well as a source of foreign exchange (Sunninchan, Mohan, and Shivanna 2005). Currently, about 35 species of *Acacia*, *Boswellia*, and *Commiphora* have been identified as potential producers of commercial gums/resins. But gums and resins are currently collected from only a few species (Lemenih and Kassa 2011). Gum arabic is an exudate (oozed naturally or tapped by humans) from the stems or branches of *Acacia senegal* and *A. seyal* (FAO 1999). 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* (Farah 1994; Hassan et al. 2011). Gums and resins are produced even in the arid and hyperarid drylands. For instance, the best and most expensive frankincense is harvested from *Boswellia papyrifera*, *B. frereana* and *B. sacra*, species endemic to northeastern Africa. *Commiphora myrrha* is endemic and confined to the dryland triangle of Ethiopia, Kenya and Somalia.

The world demand for gum arabic in 2020 is projected to reach 150,000 tons (FAO 2010) and Africa is the world's leading producer and exporter, contributing around 70 percent of global exports in 2010 (UNCTAD). The high demand is for gum arabic ingredients in various products ranging from paint to soft drinks. Sudan has the largest plantations of *A. senegal*, with well over 100,000 hectares (Chamshama 2011). In 2010, a report by United Nations Conference on Trade and Development (UNCTAD) indicated that the estimated production potential per year in the different countries of Africa is: Sudan 80,000 tons and just over 40,000 tons in both Nigeria and Chad.

Other commercial gums or resins of high economic value include myrrh, frankincense (gum olibanum) and hagar. Producer countries for these commodities in Africa include Somalia, Kenya, and Ethiopia. The global annual export volumes are between 2,000 and 4,000 tons for frankincense,
2,000–3,000 tons for myrrh, and about 1,500 tons for hagar (FAO 2010). In the period between 1998 and 2007 Ethiopia exported annually an average of 2,500 tons of natural gum and resin and earned US$34.1 million from them (Lemenih and Kassa 2011).

There are possibilities for value addition because first-grade quality gums and resins generate higher prices and more income. However, inappropriate methods of tapping, collecting, processing, transporting, and storing result in a very small proportion of first grade quality, leading to marginal earnings.

Appropriate policies and institutions are required to develop the markets and value chains to achieve greater benefits. These may include for example (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 the 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 (Lemenih and Kassa 2011). However, ways to engage local communities in the management, production and benefits of the subsector still need to be more seriously developed.

**Other Products**

Honey is produced in all African agro-ecologies, including the drylands. The global trade in honey is valued at approximately US$1.4 billion per annum (CBI 2009) while trade in beeswax is more limited, at US$65 million (FAOSTAT 2011). Whereas global demand for honey and bee products is growing, its supply is in decline in regions such as North America and Europe. Africa is uniquely positioned to benefit from the emerging opportunities presented by this developing trend. Internal demand for honey in many African countries is growing rapidly, as middle classes become more aware of the perceived health benefits of natural honey versus the negative health impacts of sugar consumption. The advantages of initially serving local and national market opportunities include lower transaction costs (including marketing), less stringent quality criteria and acceptability of smaller volumes, as well as reduced transactional risks overall (Bees for Development 2006).

Zambia and Tanzania are two of the largest honey exporting countries. In Zambia in 2005, 219 tons of honey were exported with a value of US$491,000 while Tanzania exported 466 tons with a value of US$674,000. In both countries, volumes exported have risen by 20–30 percent since 2001 (ITC 2006). Honey Care Africa has operations in Kenya, Tanzania, Uganda, and Sudan, incorporating 12,000 household honey suppliers into the product’s value chain. Farmers purchased the hives on credit and after repayment, the typical household
was earning US$180 to US$250 per year from honey sales. Studies have also found honey production to be profitable and growing in many countries, for example Ghana and Ethiopia.

Tree and Shrub Fodders
It is well known that a large number of dryland trees and shrubs are used by farmers to nourish their livestock. *Pterocarpus spp* and *Piliostigma spp* are two that are very common in the drylands of West Africa. Available evidence on the effect of trees and shrubs on livestock growth in drylands is mainly from researcher-managed feeding trials and shows a positive effect. For example, supplementation of pasture in Zimbabwe with 75 grams of *Acacia angustissima* fed to a group of goats each day was found to result in an increase of 36 grams per goat per day (compared to a control group eating only from the pasture) (Mukandiwa et al. 2010).

Deriving rates of return to tree investments in the livestock sector is complicated by the multitude of tree species used, the duration and frequency of feeding for the different species, and the fact that trees on farm and off farm are used by many households due to open grazing systems, and these may extend for long distances. A study from the Sahel (Place and Binam 2013) did find positive correlations between the number of goats and sheep and the number of fodder shrubs on farms in Burkina Faso, but the same was not found in neighboring countries, although positive correlations were found for other types of livestock (for example oxen). Also, the value of goat and sheep production and the production value to stock ratio were positively correlated to the number of trees. So there is some evidence that private investment in fodder trees and shrubs on farm is associated with higher animal stocks and production in the case of ruminants.

Practices That Focus on Natural Resource Services—Regeneration and Planting

Soil Fertility (Rotating or Intercropping Trees and Crops)
Trees of all types have some properties which are beneficial for soil conservation and fertility, chiefly through the root systems which help to hold soils in place, the litter that falls as mulch and the organic matter that the roots and litter provide to micro and macro fauna in the soil. Many farmers have known and appreciated these properties for generations. At the same time, trees can compete with crops in terms of nutrients, water and light. So farmers weigh the benefits and costs in associating trees with crops and make decisions on tree species and densities in their crop fields as compared to other farm niches. Trees in crop fields may also compete with animal ploughing, by imposing additional time and costs. Cultivation with “clean” fields is often the message that extension agents convey to farmers (Smith 2010).

Quite a number of tree species have been found to offer significant benefits to soils with relatively little competition with crops. The kingpin for the African
drylands is *Faidherbia albida* (formerly *Acacia albida*) which fixes nitrogen, has a deep rooting system, has a light canopy and drops its nitrogen rich leaves onto the soils in advance of the rainy season. There are many other useful species for soils as well, often the same ones which are beneficial as fodder (such as many of the *Acacia* species).

In the drier zones of less than 600 millimeters rainfall, virtually all of these soil fertility trees are established by farmer-managed natural regeneration. In the more humid reaches of the drylands, where population densities are mainly higher and the incentives and capacities for intensification are higher, there have been successes in establishing soil fertility trees through planting by hundreds of thousands of farmers (Garrity et al. 2010). A recent study (Kabwe 2010) found that most farmers exposed to the improved fallow technology in Eastern Province Zambia were still practicing it 10 years later.

A meta-analysis of studies on the effects of fertilizer trees on maize yields found that they often have significant positive effects in the area of a doubling of yields (Sileshi et al. 2008). However, results vary and species choice and management are critical factors as are environmental conditions. Two recent studies have been made (Glenn 2012; Place and Binam 2013) to study the yield and profit effects from farmer-managed natural regeneration (FMNR) in Malawi and the Sahel, respectively. In both cases, *Faidherbia* was a common species, and in the case of Malawi, the dominant species. Both studies found positive effects on yields from the trees alone and, due to the low labor requirements, profits as well. The millet/sorghum yield effects of FMNR, as practiced by farmers, were between 16 percent and 30 percent in Mali, Burkina Faso and Niger, controlling for other inputs and conditions (Place and Binam 2013). In Malawi, Glenn (2012) found *Faidherbia* trees to contribute 12–16 percent of maize yields on farmer fields after controlling for other inputs. The limited evidence suggests that while the fertilizer tree systems cannot shield farmers from any yield losses in droughts, they can help to provide higher yields than when trees are absent (Akinnifesi et al. 2010).

In the more humid parts of the drylands, planted leguminous trees can generate rapid yield effects because of high biomass and nitrogen produced (more than 100 kg N/ha). Regenerating native trees take longer to produce substantial effects, notably in the drier zones. In addition to the nitrogen effect from leaf biomass, there is a longer-term build-up of soil health—both biologically and physically due to the presence of the trees and the continual deposition of organic matter. This helps to create more resilience of the soil resource so that it is more productive for a wider range of crops and other plants. There is a substantial body of evidence now documenting the positive effects of agroforestry on soil carbon (for example, Beedy et al. 2014; Nair et al. 2009), soil water retention capacity (Mafongoya, Kuntashula, and Sileshi 2006) and soil fauna (Sileshi and Mafongoya 2006).

In terms of economics, several of the practices have been analyzed drawing on data from farmers and have been found to be profitable (for example, Ajayi et al.
The planted systems do require more labor inputs for establishment and to manage potential competition with crops where exotic fast-growing species are used. However, the added labor costs are more than compensated through higher yields using averages from empirical research. Ajayi et al. (2007) found that the net present value from a five-year improved fallow rotation (two years fallow followed by three years of maize) was between US$270 and US$310 per hectare as compared to US$130 for the conventional system with no fertilizer. Although a system with full doses of fertilizer outperforms the improved fallow system in yield and net present value, the two are comparable in terms of the benefit–cost ratio and returns to labor.

**Windbreaks, Shelterbelts and Other Forms of Soil Erosion Control**

Other forms of environmental protection using trees can be observed in the drylands, including windbreaks and shelterbelts. Trees can diffuse winds and lower the impact of wind/rain speeds to minimize damage on nearby crops (Lott, Ong, and Black 2009; Sendzimir, Reij, and Magnuszewski 2011; Tamang, Andreu, and Rockwood 2010). Perhaps the most often cited example is that of the windbreak practice in Majjia Valley, Niger. Catalyzed by CARE in the 1970s, the extent of expansion was about 350 kilometers by the 1980s (Long 1989) and then about 700 kilometers by 1992 (as reported in the Christian Science Monitor).

Many of the other practices described above and below will also generate protective services for soils, via canopies that intercept rainfall and break winds, via shrubs that trap soils as they move from surface runoff and via roots that help keep soils intact and improve water infiltration. Examples of useful tree species and practices for the Sahelian zone are given in Bayala et al. (2013). In the dry sub-humid zone where farmers more actively plant trees in the locations they desire, soil erosion protection can be more effective. In drier environments relying on regeneration, the effectiveness of trees on soil erosion depends primarily on the density of trees regenerated and secondarily on the species and management of those trees.

**Tree Regeneration Practices That Generate Multiple Products and Services**

**Farmer-Managed Natural Regeneration**

**FMNR—Description and Extent of Adoption**

The main objective of farmer-managed natural regeneration is to create a vegetative cover that is commonly referred to as an agroforestry parkland system or practice depending on the scale. Parklands are generally understood as landscapes in which mature trees occur scattered in cultivated or recently fallowed fields (Pullan 1974; cited in Raison 1988). The parkland system is the dominant land use system across the West African semi-arid and sub-humid zones. In these agroforestry parklands the composition and density of the woody vegetation is altered by humans in order to facilitate its use. Most often,
parklands development reflects a continual process of species selection, density management, and tree growth.

Parklands are not limited to the Sahel and Sudanian zones of Africa. Further evidence has been assembled on the widespread use of FMNR by farmers in parts of Ethiopia (Hadgu et al. 2011), Malawi (Dewees 1995), Tanzania (Monela et al. 2005), Kenya (Oginosako et al. 2006), and Zimbabwe (Campbell, Vermeulen, and Lynam 1991). There is considerable evidence that farming households in Malawi have encouraged the regeneration of trees in fields and around their households (Dewees 1995). And recent surveys in Malawi show that 85 percent of farmers protect a wide variety of trees regenerating on their land (Nyoka 2013).

The term “agroforestry parkland” emphasizes the multiple forms and purposes of these systems. They vary considerably in terms of three variables: density of trees and shrubs, diversity of species, and the age of individual trees. Together, these shape the economic benefits that can be generated today and in the future. A healthy parkland agroforestry system would include both mature trees that provide benefits today along with some younger trees to replenish the system for the future. However, demographic, economic, environmental and social developments during the past 40 years have put serious pressure on the traditional land-use systems of the Sahel. Modern Sahelian forest laws that banned the cutting of trees without license, and the ways that they are locally enforced, discouraged farmers from engaging in optimum parkland management practices and led to the degradation of the parklands to a varying extent across the region (Boffa 1999). This was particularly the case in Niger.

During the 1970s and 1980s, Nigerien farmers faced massive tree losses from drought (affecting particularly the young trees) and human population pressures, resulting in widespread desertification of the agricultural landscape. After conventional reforestation projects failed, development projects in the 1980s began to emphasize FMNR as a way to re-establish useful trees in the desertified agroecosystems of southern Niger (Tougiani, Guero, and Rinaudo 2009). They generated a range of benefits, including a supply of dry-season fodder for livestock, firewood supplies, fruit, and medicinal products that farm households could consume or sell. Moreover, several species were retained to enhance soil fertility (Barnes and Fagg 2003).

Interest in FMNR was further stimulated in the 1990s when the successful experiences of several pilot projects were shared with government policymakers. This encouraged the government to relax the restrictive forestry regulations (Code Forestier) that had severely limited farmers’ management of their own trees. FMNR landscapes began to spread rapidly. In 2004, the Government of Niger formally recognized the trend by revising the national forestry laws to eliminate the onerous restrictions on the freedom of farmers to manage the trees that they sustained on their own land.

Tree densities and tree cover in Niger have been observed to increase in recent decades. Analysis of high-resolution images acquired during 2003–08 shows that
in the Maradi and Zinder Regions of Niger alone, about 4.8 million hectares of farmlands were regenerated through FMNR (Reij, Tappan, and Smale 2009). An estimated 1.2 million households were engaged in managing FMNR systems. Many villages now have 10–20 times more trees than 20 years ago and the agricultural landscapes of southern Niger have 200 million more trees than they did 30 years ago (Reij, Tappan, and Smale 2009). Reij, Tappan, and Smale (2009) estimate that this transformation has resulted in an average of at least 500,000 additional tons of additional food produced per year which covers the requirements of 2.5 million people.

Farmer-managed natural regeneration has been spreading from Niger to other countries in the Sahel. The US Geological Survey recently mapped 450,000 hectares of young, contiguous FMNR on the Seno Plains of eastern Mali (Reij 2011). This had evolved through a similar process as in Niger, and was accelerated during the past 15 years as enforcement of forestry laws prohibiting FMNR was relaxed. It is also now locally prominent in northern Burkina Faso. Interestingly, some farmers there are managing FMNR in more visible row patterns to avoid interference with ploughing operations (Bunch 2012).

In Senegal, the Serere people have sustained a dense cover of mature *Faidherbia albida* parklands on about 150,000 hectares of farmlands for at least the past few generations. But degradation of the tree and land resources prevailed in much of the rest of the country. The Government recently has revised its agricultural strategy to promote FMNR for land regeneration. This has led to over a dozen FMNR pilot projects that are providing the technical and institutional experience to enable the widespread renewal of regreening (Herrmann, Wickhorst, and Marsh 2013; Rinaudo 2012).

Recently, there has been a resurgence of interest by the Heads of State of the Sahelian countries in the creation of a Great Green Wall across the continent. At the first African Drylands Conference (Dakar, June 2011), scientists presented evidence underpinning the value of an approach based on a grassroots, participatory engagement of the local rural populations to expand the farmer-to-farmer dissemination of FMNR region-wide. This was supported by the World Bank and the Global Environment Facility, which are now collaborating with each of the Sahelian countries to invest a pool of US$1.8 billion dollars to implement land regeneration projects based on these community-based natural resource management systems. The declaration of the second African Drylands Week, convened by the African Union in August, 2014, urged that the drylands development community commit seriously to achieving the goal of enabling every farm family and every village across the drylands of Africa to practice FMNR and assisted natural regeneration by the year 2025.

Due to the continued expansion of agricultural land, FMNR is all but assured to play an ever-important role in overall tree management in the drylands. It can be considered a “foundational practice” that is relevant for virtually all farming systems in the semi-arid and dry sub-humid dryland zones. It has such a wide
recommendation domain because establishment costs are very low, regeneration has high success rates due to growth from rootstock, it involves species well adapted to the site environmentally and climatically, and the practice can be integrated with the full range of traditional and improved crop and management systems. Other TBS involving the planting of trees can then be built around the base of FMNR to further enrich the species portfolio on the farm.

By contrast, tree planting has more limited niches in the drylands. It is more suited to the dry sub-humid zone where rainfall is higher or the semi-arid zone where there is access to dry season water to be used in tree nurseries (for example, proximity to low lying areas). Tree planting is further induced where there are attractive commercial opportunities for specific tree species suitable to the drylands.

**Exclosures for Degraded Land and Rangelands**

The restoration of degraded land in drylands almost always requires an element of restricting its use in order for the perennial vegetation to re-establish itself. Exclosures are areas that are closed to humans and domestic grazing animals with the goal of promoting the natural regeneration of trees and grasses, thereby regenerating formerly degraded lands. Exclosure practices have been used for a long time, but have been deployed in a more concerted and widespread manner since the 1980s with the implementation of large-scale land rehabilitation and soil and water conservation programs. Examples include the watershed management program in Ethiopia and the HASHI program in Tanzania.

This type of intervention is not exclusively about trees, but trees and shrubs feature strongly in the regeneration processes and planned benefits. The costs of exclosures are mainly in the form of additional labor time collecting resources from more distant locations during the period when the land is under full protection. However, as the exclosures are intended for degraded land, it is already likely that the local population is required to seek some of those resources elsewhere. There are other costs associated with protecting the area from use in terms of voluntary or paid labor time. In a few cases, fences are erected to help protect the area from human and animal intrusion, but in the vast majority of cases protection is afforded through “social fencing.”

As part of the efforts to restore degraded ecosystems and to improve the services that they provide, communities in the highlands of Ethiopia started to establish exclosures on communal grazing lands about three decades ago. The area covered by exclosures in Tigray increased from 143,000 hectares in 1996 to 262,000 hectares in 2005 and increased further to 895,220 hectares in 2011 (Mekuria 2013). The size of an exclosure ranges from as small as 1 hectare up to 700 hectares. The Government of Ethiopia has now extended the exclosure movement nationwide, and has established a goal of developing at least 15 million hectares of exclosures during the coming decade.

In Zimbabwe, assisted natural regeneration (ANR) of woodlands has been practiced since the mid-1980s as an alternative to (or alongside of) state and/or
NGO sponsored planted woodlots of exotic tree species (Clarke, Cavendish, and Coote 1996; Wily and Mbaya 2001). ANR initiatives are undertaken communally and by individual farmers, with some farmers having up to 2.5 hectares of managed areas (Clarke, Cavendish, and Coote 1996). The objective of the ANR was to restore the woodlands and their associated biodiversity, improve pastures and also availability of wood products (Clarke, Cavendish, and Coote 1996).

Ngitili is an indigenous *in situ* natural resource management system practiced by the Sukuma people of 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, but was partly halted by colonial era tsetse fly eradication campaigns, and further discouraged by the 1974/75 “Villagization” policy of massive rural resettlement. The revival of Ngitili vegetation conservation to reverse degradation was pioneered by the Shinyanga Regional Soil Conservation (HASHI) program in 1986. New information and techniques on soil and water conservation and tree establishment were introduced in the program. An estimated total of 500,000 hectares was rehabilitated during the 18-year period, reaching 2.5 million people. This included 350,000 hectares of natural regeneration and 150,000 hectares of agroforestry interventions.

**Exclosures on Degraded Land—Benefits**

A study of the *in situ* environmental impacts of 12 exclosures varying in age from 5 to 20 years was made in Tigray (Mekuria 2013). In comparing the exclosures to adjacent grazing areas, the researchers found higher values of soil carbon, nitrogen and phosphorus, as well as species richness and biomass. In the case of phosphorus, the difference was about 40 kilograms per hectare. For all the outcome variables, the differences with the adjacent land increased with the age of the exclosure. When such exclosures are later opened up to sustainable use the economic benefits can be significant. A recent thesis found this to be the case after surveying households in Tigray. Products such as honey, forage and thatch were much more commonly harvested from the exclosure sites as compared to nearby sites which were not protected (Asres 2013).

Balana et al. (2012) calculated the economic value of exclosures in Tigray, including the value of biomass accumulation within the exclosure, the prevention of sedimentation into nearby reservoirs, the reduction in flooding of nearby cropped areas, and the increase in agricultural water from springs. They then compared these to costs, including the opportunity costs of keeping the land out of production. They found that when exclosures are used on degraded lands, they are highly attractive economically (that is, with positive net present value [NPV]). However, if the land remains suitable for agriculture, then continuing to use the land for agriculture will dominate the exclosure in terms of economic returns. Mekuria (2013) conducted a valuation of the environmental services (carbon, nitrogen principally) provided by the practice of exclosure and found the NPV to be higher over a 30-year period than continuous cropping of barley, teff or wheat.
In the Ngitili Tanzania regeneration, multiple benefits were derived from natural resources management, including safety nets (fuelwood, fruits, oil and nuts, gum and resins), fodder, fuel wood, thatch grass, poles, herbal medicine, soil improvement, and other ecosystem services. A study by Monela et al. (2005) found a total of 152 different trees, shrubs, and climber species in the surveyed Ngitili forests of the Shinyanga Region. They also found that the total monthly value of the benefits derived from the Ngitili amounted to US$14 per person. The products of highest value from the Ngitili were fuelwood, fodder, timber and woodcraft and medicinal use.

The examples above show successful cases of opening up exclosures for use by the community. To ensure that these benefits are sustainable requires good management involving a range of landscape actors, which is not always easy to accomplish.

**The Special Case of Rangelands**

The importance of livestock in the drylands, and the value of trees and shrubs as sources of feed, is well known. This was well documented in the 1980s by the work of Hiernaux (1980) and Le Houerou (1980) and has been followed up over time by others (for example, Dicko and Sikena 1992). Trees and shrubs can be the source of both staple diets (for example, for camels and goats) and for supplementary feed for diet diversity throughout the year and to meet needs of all livestock during the latter part of the dry season.

The main fodder produced by trees and shrubs are leaves and pods. These are often browsed directly by animals such as goats and camels, but there is also a significant amount of cutting and gathering of these products by livestock keepers. Many trees from the Mimosaceae family provide valuable fodder, such as Albizia anhelminctica, Acacia albida (Faidherbia albida), A. benthamii, A. brevispica, A. erioloba, A. karoo, A. laeta, A. mellifera, A. nubica, A. raddiana, A. seyal, and A. tortilis. Other species of importance are Pterocarpus lucens, Piliostigma reticulatum, and Bauhinia rufescens.

Nearly all of these native trees and shrubs are established through natural regeneration with or without additional management to encourage survival or regrowth. A key factor is the predominance of free grazing systems, which can threaten the survival of these palatable young trees. Furthermore, because private rights to such species are not secured, farmers may not protect emerging fodder trees even on their own fields because they may not be able to benefit from that protection due to cultural norms allowing free grazing. When farmers have no incentive to protect natural regeneration the potential is not realized and the pressure on trees outside of farms for fodder sources is further intensified.

The importance of trees goes beyond the direct provision of feed. Trees in rangelands and pastures can also improve the quality of the herbaceous plants below them (Treydte et al. 2007; Woldeamanuel 2011). The grasses below trees (equally for nitrogen fixing and other trees) had higher nutrient contents (N, P and SOM) than grasses outside the canopy, and this held for the drier and...
lowest fertility sites in South Africa. This can occur due to the litter effect, the shade effect in retaining soil moisture in drier environments, and possibly a moisture effect due to hydraulic lift through tree rooting systems.

Many institutional responses that target grazing practices have been used to address the issue of ensuring the long-term provision of tree fodders and other forages. A common innovation is to prohibit grazing on certain areas of land for a number of years to enable regeneration of the vegetation (for example, exclosures which are discussed above). A set of communities will work out a system of rotation for these areas to enable access to enough grazing land in the short term while conserving resources for the future. The converse of an exclosure is an enclosure where livestock are congregated for periods of time. This can have a positive effect on tree regeneration in that seeds which pass through animals and come out in manure will have an increased chance of germination (Reid and Ellis 1995).

**The Special Case of Community Conservancies**

The term “community conservancies” may be seen in the context of this book as a special type of exclosure that has as a principal aim wildlife conservation and eco-tourism. The drylands host most of the national parks in Africa. As such, trees are not the main purpose of the investment, but they play an essential role in the value of the conservancy (for example, in providing fodder and shade to animals, as hosts of birds, additional sources of commercially important or useful fruits and other foods for local people, etc.). Conservancies are most popular in countries with more developed tourism industries. For example, there were an estimated 76 community conservancies in Kenya as of 2011, virtually all of which are located in the drylands (Ecotourism Kenya 2012). Fifty-one of these have tourism enterprises.

Namibia now has 64 community conservancies, covering about 17 percent of the national land area (Conniff 2011). These often combine livestock production activities with wildlife conservation. The production from livestock provides a livelihood, as does hunting and tourism. According to Conniff (2011), one factor behind the success of community conservancies in Namibia is the very low rural population density (6 persons per square kilometer), which favors labor-saving investments such as conservation and also can accommodate mixed livestock and wildlife populations. Another factor behind the success is likely to be the policy support for community-based conservancies by the government, which led to the formation of the multi-stakeholder Namibian Association of CBNRM Support Organizations, in which 14 nongovernmental organizations (NGOs) are members. Moreover, as there is little cultivation of land for crops, there is minimal conflict between wildlife and cultivators.

Overall, conservancies earned about US$5.3 million in direct income and generated about US$40 million for the Namibian economy in 2009. A separate study from Kgalagadi South District of Botswana found that community enterprises achieved an average of US$3,590 from hunting and US$8,735 from
tourism per year with a total estimated value to the District of US$191,256 (Madzwamuse et al. 2007).

In Zimbabwe, the well-known Community Areas Management Programme for Indigenous Resources (CAMPFIRE) has been in operation for several decades. Areas under CAMPFIRE are estimated to occupy about 11.2 percent of the land area in Zimbabwe. Another 2 percent of land is estimated to be under other forms of community conservancies (Rukuni 2013). This community-based natural resource management program works with Rural District Councils, which, on behalf of the communities living on communal land, are granted the authority to market access to wildlife in their district to safari operators. The tourist companies then operate hunting or viewing packages to tourists. According to Frost and Bond (2008), between 1989 and 2001, CAMPFIRE generated over US$20 million of transfers to the participating communities, 89 percent of which came from sport hunting. The District Councils are to pay the communities a dividend according to an agreed formula, but payments are not always timely or received in full.

A key question is whether the community conservancy approach can be scaled up and be profitable for new investors. One caution from Frost and Bond (2008) is that in the case of Zimbabwe, the scale of benefits varied greatly across districts, wards and households.

According to these authors, 12 of the 37 districts that had been marketing wildlife tourism accounted for 97 percent of all CAMPFIRE revenues between 1989 and 2001. Thus, many depended on donor or volunteer support for survival. From a private revenue perspective, the potential for growth in conservancy numbers depends critically on growth in demand for tourism and the degree to which such demand would be accommodated through existing conservancies and national parks.

**Environmental Services from Regeneration Practices**

In addition to the private benefits from the restoration and regeneration practices described above, there are also environmental services provided to other stakeholders that may attract payments. Carbon sequestration occurs with tree growth, mainly in the wood of the tree but also in the root systems, and in an increase in soil carbon. In the drylands, tree growth is slower than in humid areas. For regeneration practices where tree densities are low and management less intensive, one might expect on the order of 1 ton of carbon accumulation in above-ground biomass per hectare per year (Beedy et al. 2014). Trees can also add to soil carbon through their roots and leaves. However, while there is a straightforward relationship between above-ground woody biomass and carbon, it is much more difficult to assess soil carbon build up. Moreover, soil carbon stability is susceptible to change due to tillage and cropping practices. Thus, in terms of ability of dryland farmers to benefit from carbon finance schemes, the above carbon sequestration through woody biomass is likely to be the focus.
Given a typical carbon value added of 1 ton per hectare, this will generate US$10 or less of carbon value given current prices. Due to transactions costs, only a portion of this would make its way to the farmer or community. There are several examples of REDD+ programs, in the form of protection of existing woodlands that are operating in the drylands, but programs which seek carbon sequestration as a main goal generally favor more humid areas where biomass growth is faster on a per hectare basis, which is how monitoring costs are normally calculated.

Restoration and exclosures also provide water and watershed services. Many of these effects are localized, such as spring rejuvenation, but others are felt further downstream such as erosion and sedimentation control and aquifer replenishment. A study of woodlands in semi-arid and arid areas reckoned that a canopy cover of 3.5 percent to 6 percent would suffice for conferring the surface runoff regulation benefits of the woodlands to the rest of the land (Shivdenko, Barber, and Persson 2005). Whether such benefits are significant and can be compensated depend highly on the location of the landscape vis-à-vis other users of the water services. Willingness and capacity to pay for services are higher where (i) the water is used by a major city, (ii) the water is used to generate electricity or (iii) the water is used for high-value irrigation. Many “water towers” for cities and agriculture are situated in the more humid zones, but the dryland areas downstream are vital to protect the quality of water from these upper watersheds.

Tree vegetation cover in the drylands may also reduce wind speeds and dust loads. African drylands contribute over 50 percent of total global atmospheric dust circulation and have dust concentrations considerably higher than any other regions of the world (Engelstaedter, Tegen, and Washington 2006). In addition, high child mortality associated with respiratory illnesses, especially in Africa, has been partly attributed to exposure to dust (Romieu et al. 2002; Smith, Corvalán, and Kiellström 1999).

Finally, biodiversity benefits have been clearly identified and quantified in many restoration interventions. This is well noted in the case of tree species, but also for other flora and fauna. In the case of wildlife-based regeneration/conservation systems, the value of this increased biodiversity can be quantified in terms of increased tourist receipts. However, for many types of smaller, localized restoration efforts, the biodiversity values (for example, in pollination or pest regulation services) are not well quantified.

Management of Existing Woodlands

The dry woodlands in Africa comprise varied types in West, East, and Southern Africa. The Sudanian woodlands form a narrow belt below the Sahara extending from the Atlantic to the Indian Oceans. In Southern Africa there are vast miombo woodlands and mopane forests. Edible plant foods can be found in all major woodland types. However, as noted by Timberlake et al. (2010),
variation in species among the different woodlands provides different products and therefore different income opportunities. The Sudanian woodlands contain species bearing exudates such as gum arabic, myrrh, and tannins, which are less common in other woodlands.

About 320 million people depend on Africa’s dry forests and woodlands to meet many of their basic needs (Petheram et al. 2006). Economic valuation studies of wild products consumed by woodland users show that in some cases, household benefits exceed several hundred dollars per annum (Campbell et al. 2002; Chipeta and Kowero 2004; Cavendish 2000; Shackleton and Shackleton 2004). In some West African countries, bushmeat provides 25 percent of protein requirements and can be the principal protein source for some indigenous groups (Bennett and Robinson 2000; Fusari and Carpaneto 2006). In addition to habitually used products, the woodlands are stores of wealth in terms of food or income sources during hunger periods or when unpredictable adversities strike (Arnold and Ruiz-Pérez 2001; McSweeny 2004; Takasaki, Barham, and Coomes 2004).

In terms of the commercialization of woodland products, several studies have shown that the amount of household income generated by sales of woodland products in the drylands ranges between 10 and 25 percent among households with access to woodlands (Cavendish 2000; Ndoye, Ruiz-Perez, and Eyebe 1997; Vedeld et al. 2007). One reason could be the varying species composition of woodlands. Sioe, Chidumayo, and Alberto (2010) present data from Zambia showing that in spite of a large diversity of timber species, only 12.4 percent of woodland biomass comprised nationally classified commercial tree species. Low growth rates also reduce the commercial value of wood products, and long cutting cycles are required to achieve a sustainable yield.

At the same time, there is compelling evidence that a large number of entrepreneurs and their labor forces are actively engaged in the harvesting, transformation and sale of woodland products. According to Bikarong (2007), the production of fuelwood, small timber, and other products provides 6,273 permanent and 60,000 temporary jobs in Burkina Faso; employs 768 people in the public sector and 7,710 people in the private sector in Niger; and provides employment for 12,700 people in Senegal.

Prospects for scaling up commercialized opportunities for woodland management therefore appear to be mixed. In other developing regions, the potential growth in enterprises around woodland management is high, due to demand for these products and also to tenure reforms bringing more land under the control of communities (Molnar et al. 2011). However, tenure change towards community management of forests has been slowest in Africa. Moreover, recent trends in forest/woodland cover show that it is still declining in dryland Africa. Among 16 African countries dominated by dryland areas, woodland area declined in all of them between 2005 and 2010, with losses of more than 1 percent in seven of them (Botswana, Ethiopia, Somalia, Tanzania, Zimbabwe, Burkina Faso and Niger; FAO 2010).
Tree-Based Production Systems and Resilience

The 10 TBS described above contribute differently to resilience to climate and other shocks. These are discussed below under the specific resilience channel.

Reduction to shocks. No single intervention at household level can prevent exposure to weather shocks or economic shocks, which are largely exogenous to households and even communities. But some TBS, such as improved woodland management, exclosures, and FMNR, can possibly reduce exposure to some risks when practiced at scale. Such shocks may include the risk of emergence of attack of certain pests or diseases (given increased biodiversity in wooded areas). Through regulated evapotranspiration, they may also contribute to reduce exposure to drought, again, if practiced at scale. Finally, improved vegetation cover through trees may reduce the severity of wind-induced sand and dust storms. Other types of resilience benefits of TBS are best described as reducing sensitivity to shocks.

Reducing sensitivity to shocks. Winds can become destructive, temperatures may rise sharply and rainfall may stop, but in all cases many TBS can help to reduce sensitivity to them. They do this by reducing wind speeds—through windbreaks or other semi-dense patterns of mature trees, by reducing ground level and soil temperatures—through shade, and by increasing soil moisture and by inducing better soil water holding capacity, and in some cases a hydraulic lift effect. Almost all species can provide these types of benefits in their immediate vicinity; the scale of effects will depend on the size and density of trees. In addition, litterfall from trees provide valuable organic matter to dryland soils (or may do this indirectly as fodder consumed by animals resulting in manure). Some of the litterfall may further be high in nitrogen and possibly other nutrients and minerals. By helping to promote soil fertility, these also reduce sensitivity to climate shocks in providing some resistance against depressed crop yields. In the drylands, naturally regenerated species play this key role, whether in woodlands, conservancies, in communal exclosures or on-farm (FMNR).

In terms of reducing sensitivity to economic shocks, the effects noted above arise because of the general ability of trees to maintain value during shocks. During droughts for example, there may be near complete failure of annual crops with shallow rooting systems. However, more deep-rooted trees are able to tap into additional water sources and may thus be able to still generate some product, such as leaves and fruits. And some provide these during the dry season and can compensate for harvests which do not meet the year-round requirements of households. They thus help to strengthen a household’s diversification strategy in a way that is positive towards climate shocks. Also, should some crops fail, the prices of available foods such as those from trees will automatically rise, therefore providing the household a countervailing income buffering mechanism.

Increasing coping capacity. There are many examples of TBS enhancing the coping capacity of households. Trees are hardy natural assets mainly due to their deep roots. Even as a domesticated plant, they do not require much in the way
of maintenance labor. In the drylands, some trees are known to live for more than two centuries (for example, baobab, shea). The deep roots and ability to endure over long periods of time mean several things for resilience: (i) that households can count on them for contributions in their medium- to long-term planning horizons, (ii) that the non-wood producing trees will provide benefits in almost all years, and (iii) that the standing wood volume is non-decreasing over time providing a store of “wood wealth” which can be tapped into at any time for home consumption or income. The income effect is muted by the usual supply—demand forces so that if many households try to earn income through wood sales during hardships, prices will decline. The entire list of TBS above would be considered to contribute to coping capacity of households. The higher-value tree products will be particularly useful for generating income when other livelihoods face a shock—the typical portfolio diversification argument. The food and fodder bearing trees will be very important when shocks still hit the households hard (for example, high temperatures, prolonged drought) resulting in losses in other agricultural enterprises.

It is important to mention that while these TBS do play such important resilience roles, over the long term, this can be maintained only through continued rejuvenation of the tree populations. The productivity of aging trees is less than at full maturity, while their competitive effects with crops (for example, large canopies) can be relatively high. Concern has been raised by several authors (for example, Boffa 1999) about the aging profile of trees in some parklands of the Sahel, which raises the importance of actively promoting practices such as FMNR.
In selecting tree-based production systems (TBS) to examine in greater detail—notably in terms of their various costs and benefits—the following criteria were considered:

- Scale of relevance to the African drylands
- Diversity of TBS
- Available data to provide detailed economic/investment analysis

All were considered to be important, and the criterion on data availability turned out to be the most limiting one in many cases. Simply put, there is a paucity of data on TBS globally, and especially in Africa, and even more so for many lesser known indigenous species. Thus, the number of cases where sufficient data were available was low. The case studies selected are:

- Farmer-managed natural regeneration
- Shea, cashew and mango among non-wood tree products
- Timber production

In the case of non-wood tree products, these are supplemented with more concise evidence from other commodities, as there are dozens of products which are at least regionally promising.

The following five sub-sections present in order the following TBS case studies:

1. Farmer-managed natural regeneration
2. Shea
3. Cashew
4. Mango
5. Timber
In three of the case studies, farmer-managed natural regeneration, mango and timber, a similar 20-year cost-benefit analysis is undertaken to derive returns for farmers investing in those TBS. The models are based on data from the Sahel for farmer-managed natural regeneration (FMNR) and from Kenya for mango and timber. But the data are varied in scenario analysis to be relevant to other locations. The case studies on cashew and shea are handled differently, reflecting the more varied investment opportunities in other parts of the value chain.

**Farmer-Managed Natural Regeneration**

**Definition and Technical Potential**

Farmer-managed natural regeneration (FMNR) was defined in chapter 2. The types of management activities that farmers carry out include: thinning of unwanted emergent trees, protection of desired emergent trees from grazing through micro structures or fencing, managing water for the young trees, taking action against insects and disease, retention of mature trees so that the rootstock may regenerate more young trees, ploughing practices that preserve emergent trees, and annual care of the regenerated trees. In the drylands, it can be argued that nearly all farmers practice FMNR to some degree but the degree varies considerably.

Surveys made on the establishment of trees in Africa find that in the drylands, the vast majority of trees on and off of farms are established through regeneration. An exemplary study on the effect of aridity on tree establishment was made using transects near Mt. Kenya (Oginosako et al. 2006), showing the stark shift from planted to regenerated trees on farms as one moves from more humid (90 percent planted) to drier environments (30 percent planted), despite the prevalence of tree nurseries in rural Kenya. The resulting tree diversity is much more skewed towards indigenous trees when regeneration is favored, whereas exotic trees are often dominant among planted trees.

The technical potential for FMNR is related to environmental conditions: in the drier environments such as SRT2, rainfall limitations make it more difficult for trees to regenerate in the absence of supplemental watering. In the same zone, there are fewer sedentary fields where rural dwellers would take such an interest to invest in regenerating a particular field. In these zones, the pastoral equivalent of FMNR, the exclosure (protecting areas previously used as paddocks for regeneration) would be practiced instead of FMNR. The other major limiting factor is the presence of tree seed stocks in the soil.

Besides environmental conditions, other factors may limit the technical potential of FMNR. There are several other institutional-related factors that have been identified as limiting the potential for FMNR, such as fire setting, free grazing, and rights and regulations over trees. Place and Binam (2013) found a large percentage of Sahelian farmers identifying unreasonable forest codes as a limiting factor (44 percent), heavy-handedness on the part of forest officers (38 percent), uncontrolled cutting of trees (31 percent) and animal damage (28 percent).
At the household level, adoption regressions were done on a Sahel sample of 1,000 households (Place and Binam 2013). Household variables such as farm size, labor, age, or education of household head were not statistically related to adoption of FMNR. Thus, the practice of FMNR does not seem to be constrained by availability of household resources. On the other hand, the value derived from FMNR may be related to household factors. A study by Sambo (2008) in Niger found that the wealthier, less vulnerable (as proxied for by access to farm land) households tended to report higher values of harvested tree products compared to more vulnerable households. A further constraint to the practice of FMNR is animal ploughing which may destroy young trees in the absence of careful and costly maneuvering (Smith 2010).

**Costs of FMNR**

By definition, FMNR does not require the effort to acquire germplasm or to propagate seeds or cuttings and nurture them into seedlings. In some cases, the cost of regenerating a tree is essentially zero—new trees emerge from the soil without need for nurturing or protection. However, establishment and maintenance costs may be required.

The more common establishment costs include protection of desired trees—mainly either in the form of micro-protection of individual trees, or protection of larger areas mainly using wood-based barriers or fences; and removal of trees not desired by the farmer—this is practiced to some degree by all farmers. Maintenance costs may include weeding—this is primarily for trees emerging from seed but is not needed for those emerging from coppices and roots because these grow rapidly; pruning and other forms of management of the canopy size and shape—this will be one of the more demanding labor needs for FMNR mainly when the trees are mature; harvesting of products—this is an obvious cost of FMNR or all tree growing practices that must be considered at about the same time as the benefit.

In terms of calculating actual costs incurred by farmers, there are three considerations: (i) how common are these activities, (ii) how much time or material is spent when they are undertaken, and (iii) what are the unit costs in terms of time or materials. In our investment analyses we use the data from Abdoulaye and Ibro (2006) on establishment costs of FMNR (24 days per hectare) and World Agroforestry Centre (ICRAF) expert opinion on maintenance costs (3 days per hectare). Although the scaling up of FMNR in the Sahel has been labeled as farmer-driven with little external support, a number of programs are now investing in the scaling-up of FMNR. These programs are spending resources on enhancing farmer awareness of the benefits of FMNR, building farmer tree management skills, organizing landscape management of grazing and fire, developing tree product markets, and identifying workable solutions to forest code regulations. It is too early to evaluate which of these costs are necessary and to what degree. This could be a topic of a future study since the programs will have good information on the expenditures made.
Most externalities associated with FMNR are positive. However, trees require water, and as such, there is always the concern that they may use water resources at rates which have tradeoffs with human, animal or crop uses. There is poor information on this especially at the landscape scale. Are there alternatives to FMNR? Trees can be grown off-farm, but then the *in situ* effects of trees on agricultural soils and crops will be foregone. The increased rural population, coupled with dwindling woodland, also suggests that woodland management is not an alternative to FMNR, but rather a highly complementary activity (Mayaux et al. 2004; Shumba et al. 2010).

**Benefits**
The three main pathways of private benefits are through direct human consumption of tree products, indirect benefits on crop production and increased benefits through livestock production.

In terms of direct consumption benefits from trees, the major products are foods (fruits, nuts, oils and leaves) and wood (construction and fuelwood). A recent study in the Sahel (Place and Binam 2013) found that all households harvested tree products for their consumption, and in many locations, the quantity and value was high. Table 3.1 shows that the average harvested value per household ranged from a low of about US$120 in Senegal to about US$270 in Niger. Malian households also extensively harvested tree products, and Burkina Faso was in between the two extremes. We use these averages (on a per hectare basis) in the economic model below.

Figure 3.1 shows that only a minority of harvested products were sold by households for income—the highest being about 35 percent in Burkina Faso and the lowest being about 4 percent in Niger. Burkina Faso households benefit from the presence of a wide distribution of *Vitellaria paradoxa* (shea), which has a large global market. There is a 3 to 4-fold difference in harvested value between the sites within each of the countries. These data are consistent with data collected from Niger (Yamba and Sambo 2012) which found that average harvested value varied between US$28 and US$213 in five Nigerien villages. Thus, the ratio of values of marketed to harvested tree products varies across

<table>
<thead>
<tr>
<th>Country</th>
<th>Value of harvested tree products per household (USD)</th>
<th>Value of marketed tree products per household (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burkina Faso</td>
<td>Mean 181</td>
<td>Mean 64</td>
</tr>
<tr>
<td>Mali</td>
<td>Mean 254</td>
<td>Mean 73</td>
</tr>
<tr>
<td>Niger</td>
<td>Mean 267</td>
<td>Mean 12</td>
</tr>
<tr>
<td>Senegal</td>
<td>Mean 119</td>
<td>Mean 37</td>
</tr>
</tbody>
</table>

*Source: Place and Binam 2013.*
country and are below 0.4 in all cases. As a result, the contribution of tree-based revenue to total household revenue is generally on the low side, at or below 10 percent. Burkina Faso is the exception where shea is very important as an income source.

Crop yield improvement is another major benefit pathway of trees as described in chapter 2. It is important to note that in the Sahelian countries, chemical fertilizer use is low both in percentage of farmers (25–30 percent) and in amounts applied (Burkina Faso is an exception, due principally to the maize growing region in the southwest). Manure is a much more common input (55–80 percent of farmers). Trees are found throughout all farms, but the density and age profiles of those with known beneficial effects on soils (“fertilizer trees”) vary across sites. Both are important, for it is the older trees which have the significant effect on yields. In Niger, the mean number of mature fertilizer trees per hectare was 32 while in Mali and Burkina Faso it was lower at about 5. After controlling for other effects (rainfall, soil type, seed density, area, manure, fertilizer), it was found that the mature fertilizer trees alone explained 15–30 percent of cereal yields in Niger, Mali and Burkina Faso (no effect was found in Senegal). Furthermore, there is a positive correlation between the presence of mature fertilizer trees and the amounts of manure and fertilizer applied (between +0.15 and +0.4). That is, farmers tend to apply more manure and fertilizer on fields with a higher density of trees.

Considering only the direct effect (of 20 percent contribution), this amounts to about 60 kilograms of millet per hectare in Niger, 120 kilograms of millet per hectare in Mali and 150 kilograms per hectare of sorghum in Burkina Faso.

In Malawi a study of maize yields under *Faidherbia* (mainly regenerated) was conducted in 2010 (Glenn 2012). Controlling for other crop inputs, she found an increase of 12–14 percent of maize yields in the fields with *Faidherbia*—from

![Figure 3.1 Importance of Tree Revenue in West Africa](image-url)
a without case of about 1,350 kilograms per hectare. A calculation found that the optimal number of trees per hectare to maximize yields is 40, while the average density among the sampled farmers was only about 10.

Haglund et al. (2011) undertook a study of more than 400 farmers in Niger, comparing those who practice FMNR against those who do not. Their figures suggest that the gross value of crop production for farms practicing natural regeneration was US$138, compared to US$88 for those that do not practice natural regeneration.

Among the key environmental benefits from FMNR, three are partly internal and are captured to some extent by the landholder and included in the investment analysis.

1. Soil conservation—much is *in situ* and thus captured privately. However, because of the long lives of trees, the benefits are likely to be claimed by both the current land user and at least one other generation to follow. It also has some positive externalities on other land.

2. Shade and micro climate—this is purely *in situ* in nature, with the main gain being lower air and soil temperatures. Tree shade can significantly reduce temperature, radiation, and soil evaporation of the near surface atmosphere leading to higher soil moisture with a major impact on crop performance (Lott, Ong, and Black 2009; Ludwig et al. 2004).

3. Micro-level water effects—trees can have both positive and negative effects on water availability for other plants. On the positive side, shade affects temperature and evaporation rates in a positive way and trees can also bring water from sub-surface levels up to topsoils where other crops can use them (Bayala et al. 2012). On the other hand, trees can compete for water with other plants.

The following two environmental effects have a significant degree of positive externality and as such are not captured in the investment analysis below.

4. Biodiversity—FMNR is a major source of tree biodiversity on the landscape and as such will have some knock-on effect of biodiversity for other fauna such as birds and insects.

5. Carbon sequestration—studies have shown that trees from FMNR sequester carbon at the rate of about 50 percent of wood biomass above ground. What is also important in the drylands is the carbon sequestered below ground, in the often deep and vast root systems of the trees and in terms of soil carbon via organic depositions and more favorable environment for soil micro-organisms.

Finally, in discussing the benefits of TBS, it will be important to refer systematically to the three pillars of the conceptual framework. In other words, how do the different benefits generated by TBS contribute to (i) reducing exposure to shocks, (ii) reducing sensitivity to shocks, and/or (iii) improving coping capacity?
At the scale of a household, FMNR cannot reduce exposure to shocks such as climate change and variability, pest incidence, winds, price changes and the like. At the level of a concerted effort by communities, it may reduce the velocity of winds through vegetative cover and the spread of pests and diseases due to increased biodiversity. It does however contribute significantly to reducing sensitivity to shocks and improving coping capacity. FMNR can reduce sensitivity to shocks in the following ways: increased air temperatures can be lowered for plants and soils under the canopy of trees; the effect of low rainfall can be reduced under tree canopy due to lowered evaporation; and by improving soil physical, biological and chemical status, crops can better withstand climate change and variability. In terms of coping strategies, FMNR usually leads to the emergence of a variety of tree species which can provide alternative subsistence and income opportunities. Good examples include: fodder shrubs which produce feeds during the dry season; fruit trees that produce harvests at different times of the year; and wood products that may be sold for income anytime during the year.

**Returns to Investment**

To represent the returns to investment in FMNR, a model was constructed to analyze costs and benefit streams per hectare over a 20-year time frame. Two benefit streams were captured: value of direct tree products (wood and non-wood) and value of improved crop yields. The data on benefits are from Place and Binam (2013) for the Sahel.

Three categories of costs are included in the analysis: (i) establishment of FMNR, (ii) annual costs (upkeep and harvesting) related to tree products, and (iii) annual costs related to crop production.

In this book, we present model results for Mali and Niger, and the crop is millet. Discount rates of between 10 percent and 20 percent are used over both a 20- and 30-year time frame (for reference, Dewees (1994) used a 15 percent discount rate for a 30-year period in analyzing natural regeneration in Malawi) to develop ranges for the base model. The investment is to practice FMNR up to the average level found in those countries, starting from a base of no trees.

Table 3.2 shows the net present value and benefit–cost ratio for the six different combinations of discount rates and time periods on a per hectare basis (but all other variables are fixed). The lowest estimates for the returns, for the 20-year period at a 20 percent discount rate are US$29.9 for NPV and 1.5 for the benefit/cost ratio for 1 hectare of FMNR. The highest calculations are for a 30-year period at a 10 percent discount rate and are US$ 178.11 and 2.66, respectively. The internal rate of return (IRR) and breakeven year for the practice do not vary much for the different assumptions. The IRR is 0.34 in a 20-year time frame and 0.36 in a 30-year time frame. The breakeven point comes in year 11 with a 20 percent discount rate and year 10 and year 9 for discount rates of 15 percent and 10 percent, respectively. The benefit streams per hectare from crops and tree
Table 3.2 Private Economic Returns from FMNR
USS/hectare

|                  | 
|------------------|-----------------|
|                  | Mali            |
|                  | 20-year time period | 30-year time period |
| **NPV**          |                  |
| 10% discount rate| 133.57           | 178.11               |
| 15% discount rate| 66.82            | 82.46                 |
| 20% discount rate| 29.89            | 35.71                 |
| **BCR**          |                  |
| 10% discount rate| 2.43             | 2.66                  |
| 15% discount rate| 1.94             | 2.09                  |
| 20% discount rate| 1.52             | 1.60                  |
|                  | Niger            |
|                  | 20-year time period | 30-year time period |
| **NPV**          |                  |
| 10% discount rate| 442.80           | 568.99                |
| 15% discount rate| 253.94           | 298.24                |
| 20% discount rate| 149.18           | 165.66                |
| **BCR**          |                  |
| 10% discount rate| 6.78             | 7.47                  |
| 15% discount rate| 5.40             | 5.83                  |
| 20% discount rate| 4.19             | 4.43                  |

products are virtually the same in the case of Mali. In contrast, all the economic variables are more favorable for FMNR in Niger due to larger benefit streams from both harvested tree products and crop yields.

**Recommendation Domains**

At a coarse scale, FMNR should be considered as a recommendation in all geographical regions and particularly in the semi-arid and dry sub-humid drylands. FMNR will continue to support the largest number of established trees on farms in the drylands. Place and Binam (2013) found that over 90 percent of trees on farms in the Sahelian countries were established by regeneration.

In the dry sub-humid drylands, the importance of FMNR as a TBS remains, but tree planting opportunities are more favorable in these environments, not only for high-value trees, but also for the provision of many types of tree products and services (for example, soils, fodder).

Within a particular dryland zone, there may be further nuances on recommendations for how to practice FMNR. For example, certain institutional arrangements such as improved grazing management may be an important complementary action in some places while not in others. The types of trees that will be desirable for farmers to retain, as well as the densities of trees, may also differ across locations. For example, where fertilizer use is extremely low, promoting regeneration of trees which have known positive soil fertility properties will be more important.

Figure 3.2 shows that the density of *Faidherbia albida* varies by location with key differences observed between southern Niger and Burkina Faso. Nonetheless, it is interesting and hopeful to note that in the sites covered in the Place and Binam (2013) study, there is a relatively good number of young *Faidherbia* (less than 20 centimeters in diameter) emerging in comparison to more mature *Faidherbia*. 
Scaling Up Issues

As noted in the section on technical potential, there are several institutional-related factors that have been identified as limiting the potential for FMNR, such as fire setting, free grazing and rights and regulations over trees. The use of fire and free grazing systems generates benefits in terms of grass regeneration, clearing of debris, catching wild rodents for food and in the case of free grazing, offering a cheap mechanism for feeding livestock. Thus, it is not easy to find institutional reforms that can accommodate the interests of FMNR with others. However, practices such as controlled fires, rotational grazing areas, and the promotion of livestock corridors are all options that have been successfully implemented in the drylands.

The issue of forest regulations which create disincentives for farmers is one that is widespread in the developing world. These include the banning of felling or cutting of a number of species without obtaining a prior permit, at a fee. Violation of such regulations entails a hefty fine, and so farmers will often remove young trees from their land to avoid having to adhere to these rules in the future. Among such regulations, the adverse effects of the Sahelian forest codes have long been recognized (for example, McLain 1992) and there have been many policy dialogues in the region to try and move reforms forward. Although not initially backed by formal policy change, the recent regreening in Niger has been attributed to a significant extent by the relaxation of enforcement of such policies (Reij, Tappan, and Smale 2009). A recent analysis of the forest codes and recommendations for action are in Yatich et al. (2014).

The existence (or not) of markets for tree products is another factor that impacts on incentives to manage trees. The development of tree product markets will have a positive effect on TBS in general. For FMNR in particular, market development may have different effects. On the one hand, markets surely do
influence collection and marketing behavior of farmers as the case of shea in Burkina has demonstrated. In general, as tree product markets develop, there is more incentive to maintain trees on farms. There may be further incentives concerning the selection of species to retain based on market signals, but only if market signals persist for a long period of time since changes in tree species composition is a long-term operation in the drylands. Furthermore, in the semi-arid and dry sub-humid zones where tree planting opportunities are greater, certain types of market development may favor tree planting by farmers and, as a result, may also reduce interest in FMNR.

Shea (*Vitellaria paradoxa*)

Rural populations in Sub-Saharan Africa use shea butter as a food oil, for medicinal applications, a soap base, and a variety of cultural purposes. The fruit is also consumed, and is commonly eaten during harvest or dried for later use. Approximately 18 million women are involved in shea collection and production (Naughton, Lovett, and Mihelcic 2015).

Exports from Africa have risen over time at an annual average of about 220,000 tons (Bello-Bravo, Lovett, and Pittendrigh 2015) and with significant annual fluctuations. Peaks were observed in 2004 (263,000 tons), 2008 (350,000 tons), and 2013 (500,000 tons). Most exports were to France, Great Britain, the Netherlands, Denmark, North America, and Japan, as a lower-cost substitute for cocoa butter in confectionery and for margarines (Carette et al. 2009). Shea kernel exported as such is largely destined for industrial extraction and fractionation into olein and stearin fractions, of which the latter is used as a cocoa butter improver (CBI) for chocolate sold in the European Union. Specific countries that allow its use in chocolate include the UK, Denmark, Sweden, Portugal, Ireland, Russia and Japan (3F 2010).

Burkina Faso, Mali, Ghana, Nigeria, Côte d’Ivoire, Benin, Togo and Guinea remain the main countries of shea nut production (table 3.3). Shea kernel prices are closely linked to cocoa butter prices, given the primary importance of confectionery applications for shea stearin.

The Shea Tree and Its Growing Environment

The West African region is the source of nearly all shea exports, and is currently and foreseeably the dominant supplier of shea. Nigeria and Mali are the leading producers with Burkina Faso expanding rapidly recently due to the high numbers of shea trees.

The West Africa region has an estimated 500 million productive shea trees (Reynolds 2010) and as many as 1.8 billion exist across Africa (Naughton et al. 2015), with a production capability of at least 2.4 million tons of kernels. Shea does not occur frequently in the Sahel as such, but is most common in the dry sub-humid and parts of the semi-arid zones of the region—see map 3.1. Due to limited global demand, the scale of industrial
shea butter production for export is only a third of its actual potential production capability.

**Establishment of Shea**

Natural regeneration is the most common establishment method for shea in all 21 countries of Africa in which it is grown. Traditional management involves selective retaining and maintenance of the trees on lands that are also most often used for crop cultivation. Where farmers actively select shea trees based on their early growth, a relatively higher-yielding profile of trees in farm lands will prevail (Djossa 2007). The fallow period is a particularly favorable time for regeneration, because there is no ploughing which can destroy the trees (there is grazing, however, which is also a threat). Fallow length therefore is considered a crucial factor for shea tree regeneration (Lovett and Haq 2000; Schreckenberg 2004).

Seedlings take 2–3 years to reach field planting size, which is costly and thus discourages farmers from planting shea. Its juvenile stage lasts very long, up to 15–20 years in more arid areas, and is a major disincentive to planting. Planting may best be limited to threatened varieties (such as the Adamawa variety of central Cameroon). There is some potential for using cuttings of coppices that emerge from root systems to establish shea. High productive scions can be grafted successfully onto rootstocks using side cleft, tongue cleft, top cleft and chip budding. This greatly reduces the time to fruit-bearing. Although this is a very uncommon practice, it is a technique that could usefully be scaled up.

**Shea Value Chain**

Figure 3.3 depicts a typical shea value chain from West Africa where all end products derive from the same collectors spread across a large number of villages.
A portion of the products is for home use, while another portion will be sold for various destinations, depending on the location and connection to the commercial value chains.

The following discussion examines costs and benefits of shea first from the perspective of the collector/producer and then from the perspective of a processor.

**Production—Costs and Benefits**
Shea trees start to bear fruits at the age of 15–20 years and reach maturity from about 45 years. The trees can continue to produce fruit for up to 200 years. A mature shea tree will produce about 700 fruits per year. However, the fruits are small and the kernel yet a fraction of that. Fruit production fluctuates considerably from tree to tree and between seasons, roughly following a three-year cycle. An average fruit yield per tree was estimated at 25–55 kilograms per year by Fleury (1981). Schreckenberg (1996) calculated an average annual yield of 5 kilograms dried kernels per tree in a study in Benin, which corresponds to about 25 kilograms of fresh fruit. This would yield between 1.5 and 2 kilograms of butter. The nuts, which are embedded in a soft fruit, fall to the ground during the harvesting period—between June and August in West Africa (Ferris et al. 2001). This is timely as it is precedes the main harvest of grains.

**Costs to the Producer (Collector)**
The largest private costs shea farmers incur is the time and labor spent in collecting the fruits and processing them first into viable kernels and then sometimes into
butter or oil. The overall time taken is divided between collecting, boiling, drying and cracking. Estimated times for these activities varied considerably; the mean time spent to produce one bag (90 kilograms) of nuts was between 58 and 72 hours, or between 7 and 9 days (Kent and Bakaweri 2010). Traditionally, shea nut harvesting and processing are rural women’s work. Women gather shea, walking varying distances with head-loads occasionally surpassing 25 kilograms of nuts (Carney and Elias 2006). A study by SNV (2010) found that women would spend just under 6 hours per day collecting shea fruit and on average collect 31 kilograms, meaning that it took on average about 11 minutes per kilogram of fresh weight, including the time spent traveling to and from the harvesting sites.

Collectors in West Africa almost always take the process one step further, to parboil the seed in order to separate the shea kernel and stop the germination process of the nut. This process does not require much labor for boiling or shell-ing time per kilogram, but does require water and fuelwood, the latter of which entails some material cost of about US$3 per 90-kilogram bag of fruit (SNV 2010). Additionally, accessing water can be problematic or costly when carrying out shea butter extraction during the dry season in villages where sources are seasonal or distant. The women will also convert some quantity to shea butter for home consumption. This is a very labor-intensive process, often taking a day to produce a sufficient amount for home use or for local sales. It can take 4–6 women a full day to produce 4–5 liters of shea butter from 20 liters of nuts. Shea olein is yet another valuable derived product used in cosmetics, but that is produced by industrial firms.

Since shea processing by traditional methods requires significant amounts of firewood and water this creates pressure on those resources.

**Benefits to the Producer (Collector)**

The amount collected by an individual collector per day (31 kilograms of fruit) translates into about 15 kilograms of kernels, which is in turn about one-fifth of an 85-kilogram bag of shea kernels. The value of a bag fluctuates by location and year, but the export price from West Africa is currently between US$350 to US$500 per ton, which translates into about US$36 per 85-kilogram bag. For a day’s collection this is about US$7 that would be shared between the collector and others along the chain.

Export markets have generally been expanding for shea. In Burkina Faso, sales to a major shea buyer, L’Occitane, increased from less than 100 tons in 2003 to 660 tons in 2013, generating about US$1.3 million in farmer revenues (for about 15,000 women). In addition, in 2011, 2 percent of the sales price from shea went into Fair Trade-backed community funds, which is used to finance community development initiatives.

Shea is also an important part of the ecosystem in which it resides. Birds nest in the tree, bats eat the fruit, often carrying away the seed for dispersed regeneration of the species, and in a region that is seeing desertification expand, the shea tree is resilient to the harsh climatic conditions. Shea trees also present the
opportunity to sequester carbon. No studies have been conducted on the amount of carbon that a shea tree can capture, but with an estimated 500 million productive shea trees across the region, and considering the 200-year lifespan of shea, the amount of CO₂ sequestered by the shea tree is substantial and presents an opportunity to tap into possible carbon sequestration schemes (UNDP 2010).

**Processing of Shea Kernel into Shea Butter**

**Manual (Traditional) Processing vs. Modern (Improved) Processing Methods**

The manual processing procedure—with little capital or equipment—is the most commonly used method to convert shea kernel into butter, which is mostly used for home or local consumption. Since there are a number of steps required to be completed within a day (breaking, roasting, pounding, grinding, beating/kneading, boiling), the maximum amount of shea kernels which can be handled at a time by an individual is about 10 kilograms—which may make 3 kilograms of butter.

The major costs associated with manual processing are for equipment—cooking pots, mortars and pestles, and pans. At 2004 prices, coupled with the labor cost of collecting the nuts, this would translate into an initial investment cost of US$213 (US$70 for equipment and US$143 for inputs and overheads) in year 1. With a yield of 240 kilograms a year translating to revenues of US$192 a year, the break-even point would be achieved in year 2. Under a partly mechanized processing method, involving additional investment in roaster and mill, production quantity can be increased, and break-even can be achieved in year 1 itself.

Although automation is more efficient and would lead to greater quantities being processed and sold in the market, its expansion needs to be tailored to supply and demand conditions; areas of both excess supply and excess demand are present across Africa. Furthermore, constraints in semi-automated processing are the combination of high fuel and maintenance cost according to prices in 2008, which made shea butter extraction unprofitable. Manual processing relies on local available resources and is therefore a sustainable business (Carette et al. 2009).

A 2001 study in Uganda on shea oil processing shows no capital costs, with the bulk of costs going towards the shea kernel, firewood, water and labor. A profit margin ratio analysis shows a margin of 30 percent for the traditional processing method, versus 26 percent for an automated process (Ferris et al. 2001). In addition to the profits generated, the traditional method is an important source of income for women, who have fewer employment opportunities in rural Uganda than men.

Most of the shea butter currently exported from West Africa is procured by export agents directly from the pickers or a network of local intermediaries without regard to quality and there is no quality premium paid to the producer to reward her efforts at producing an improved quality shea kernel. Ghana is the only country that has attempted to establish such a system, but there remain difficulties with its implementation. Improving quality through price premiums or other rewards would therefore be a key challenge for an investment program to address.
**Recommendation Domains**

Shea grows abundantly through natural regeneration and production potential for shea trees far outweighs the current demand for shea products. The maintenance and regeneration of existing stands is therefore a key production recommendation. Considerations for the expansion of shea trees would be limited to areas that offer a competitive advantage for production of high-quality shea and relatively good accessibility to large markets or processors. One such area may be in dry sub-humid Ghana—exploitation of existing shea is approaching maximum potential while market mechanisms for exporting shea are best developed here. Neighboring coastal countries of Togo, Benin, and Nigeria also offer attractive opportunities for expansion. Elsewhere, recommendations for tree establishment are for the long term, to provide for replenishment of aging populations. In most locations, the replenishment will be through FMNR and will satisfy the large local demand for shea products. In the dry sub-humid zone nearer to ports, the wider use of valuable propagation methods of superior material (for example, higher yielding trees) could be tested given that exported shea needs to be of relatively high quality. The reason for this is that through FMNR, studies have found the productivity of shea to vary enormously across individual trees. For example, Boffa et al. (1996) found that 50 percent of mature shea trees accounted for 85 percent of total production and almost 30 percent of trees were unproductive.

Among other types of recommendations, increasing productivity through improved management can be recommended in all shea growing areas. Since shea is consumed throughout the growing area, improving effectiveness of manual processing methods can also be recommended everywhere, to save time for women (again, see below). Recommendations for large-scale processing investments cannot be clearly articulated from literature reviewed to date. However, Ghana has already established itself as a main source and export hub for the West Africa region, and thus is well positioned to expand processing at scale.

**Key Factors in Scaling Up and Investment**

In terms of scaling up investments, there are those related to production and those related to post-production investments in the shea products value chain.

**Production Investments**

Productivity can be increased through improved management. At early stages of regeneration, protection from browsing, ploughs and fires can enable the trees to focus on growth and can lead to fruiting times several years earlier than if the trees are subjected to injury. During maturity, good pruning methods can also help to raise fruit production levels as opposed to non-pruned trees.

An issue concerning existing and future trees is quality of kernels and butter. The quality of shea butter produced by small-scale processors is often not up to international standards, due to the lack of adherence to formalized standards. This problem is related to the abovementioned lack of means for rewarding quality throughout the shea value chain. Product quality of shea kernel and
shea butter depends heavily on postharvest handling and processing at the primary processor level. There is potential for improved efficiency at the level of aggregator or raw nuts where training and price signals may be most effective (Masters 2014).

Investments in integrated shea conservation and product development projects can benefit not just shea producers, but also the community they are based in as a whole. A good example of such an approach is the Shea Project for Local Conservation and Development of northern Uganda (1992–2002). The project was an integrated, long-term effort to preserve the ecological integrity of savanna woodland in northern Uganda through reinforcement of the economic importance of the shea butter tree. Covering about 10,000 square kilometers, and working with over 400 community-based (mostly women’s) groups the Shea Project undertook a holistic and landscape-level approach to market-based product development, seeing that such economic incentives provide a powerful engine for survival of the shea tree based on local livelihoods, with multiplier effects enhancing the health of the ecosystem in which they occur in (Masters, Yidana, and Lovett 2004).

**Processing Investments**

Traditional manual methods are used to process about 60 percent of all shea butter produced in West Africa, at an extraction rate of just over 30 percent. Mechanized processing, in comparison, can achieve higher extraction rates if hexane extraction methods are used. The Nununa Federation in Burkina Faso, by mechanizing certain parts of the butter production process, oversaw the reduction in production time which dropped by 40 percent between 2009 and 2011 (Uniterra 2012). However, current processing methods are overwhelmingly manual in nature, since equipment for semi-automated or wholly automated processing is either not available, or is hard to procure due to high costs and lack of credit facilities. A microfinance program with results such as those reported from a study in Ghana by Effa and Herring (2005) can facilitate the adoption of shea butter processing technologies by rural women. An extension-training program for new shea butter processing methods is another investment option to promote better processing.

Mechanized processing yields 30–35 percent of shea butter from parboiled shea kernel in West Africa. In 2004, 13 processing plants in the region had the capacity to convert 162,000 tons of kernels into about 50,000 tons of shea butter, at an extraction rate of 31 percent (Addaquay 2004). A US$10 million shea processing plant was opened in 2012 in Ghana. The investment was made by the Produce Buying Company of Ghana with a capacity to handle up to 40,000 tons of shea nuts per year (Global Shea Alliance 2012). However, operations at the plant have not proceeded without difficulty and it has been shut down for a large part of 2014. Indeed, most of the West African plants produce at levels less than 25 percent of their installed capacity. Many operate for no more than six months
of the year, due to the unavailability of supply or the high cost of storing shea kernel throughout the year. Investments at various parts of the value chain, such as in more energy-efficient processing, are thus needed to make processing more efficient and profitable (Lovett 2004). Value chain investment to stimulate higher quality of shea butter production is where the priority should lie for countries with underutilized supply of shea, such as Nigeria.

The increased use of shea in the personal care and cosmetic formulations can constitute a significant area of product diversification for shea producers, though typically the percentage of shea butter used in such formulations is very limited. As of 2010, chocolate and confectionery products accounted for 90 percent of the demand for shea butter, compared to just 10 percent by the cosmetics industry. The chocolate manufacturers prefer to import the raw shea nuts and process them into butter themselves, due to price considerations and the need for further post-extraction processing (for example, de-acidification, deodorization and fractionation). Whether this product transformation could be undertaken in West Africa could be explored.

**Cashew (Anacardium occidentale)**

Cashew is a global success story with export trade having nearly trebled within the decade from 1998 to 2008, from 243,000 metric tons (MT) to over 707,000 MT. In 2011, according to FAO estimates, Sub-Saharan Africa produced over 1.8 million tons of cashew nuts (with shell), a near 100 percent increase from 2003 production of 934,000 tons (table 3.3 below). There are an estimated 1.5 million cashew growers in Africa, mostly smallholders (African Cashew Initiative 2012). A key growing zone for cashew is the dry sub-humid zone but it extends also into semi-arid areas. Map 3.2 shows current cashew growing countries.

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<td>1,583,473</td>
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Cashew is a global success story with export trade having nearly trebled within the decade from 1998 to 2008, from 243,000 metric tons (MT) to over 707,000 MT. In 2011, according to FAO estimates, Sub-Saharan Africa produced over 1.8 million tons of cashew nuts (with shell), a near 100 percent increase from 2003 production of 934,000 tons (table 3.3 below). There are an estimated 1.5 million cashew growers in Africa, mostly smallholders (African Cashew Initiative 2012). A key growing zone for cashew is the dry sub-humid zone but it extends also into semi-arid areas. Map 3.2 shows current cashew growing countries.
West African countries, notably Côte d’Ivoire and Nigeria, account for about 25 percent of global production (Boillereau and Adam 2007). Recent decades have seen a fall followed by a rise in Africa’s position as a supplier of cashew to the global marketplace (see figure 3.4). Since the mid 1990s, Nigeria has emerged as the leading cashew producer in Africa, and since 2003, the production of cashew nuts (with shell) in Nigeria has increased almost 60 percent, from 524,000 tons in 2003 to 835,000 tons in 2011. Other countries have also witnessed rapid growth in production (see table 3.3). As of the late 2000s, only about 10 percent of cashew production is processed each year within the region with a processed retail value of about US$134 million. African cashew producing countries currently export a bulk of their cashew production, often to countries in South Asia, for processing, which leads to a considerable loss of value addition revenue for those countries, as much as 42 percent of the final product. Furthermore, a study from Mozambique in 2003 estimated that processing
cashews in-country could increase producer prices by at least 25–50 percent (HORUS-Enterprises 2005).

**Cashew Production**

Cashew trees bear their first harvest at around 5 years, reaching peak productivity at between 10 and 15 years, and tailing off at around 40 years. With good germplasm and management, 7–11 kilograms per tree are attainable but yields in Africa are much lower (ACA 2010; FAO Azam-Ali and Judge 2001). Cashew grows on very poor sandy soils, is drought-tolerant, and is commonly intercropped with cultivated food crops such as cassava, thus providing a buffer against the failure of rainfed annual crops in a context of climatic uncertainty (Mitchell 2004). From an ecological perspective, the cashew tree has been shown to have high potential for the restoration of severely degraded lands (Dick et al. 2015). Cashew requires rainfall of at least 600 millimeters per year and so the tree is primarily suited to the dry sub-humid zone.

**The Costs of Cashew Production**

In a smallholder cashew production system, the primary costs incurred by the smallholder are inputs costs—purchasing germplasm and fertilizer—and labor.
costs. In Mozambique, INCAJU estimates that the cost of good quality cashew seedlings for a hectare would be about US$50, which in their opinion will not significantly influence the willingness of farmers to plant cashew trees (Große-Rüschkamp and Seelige 2010). Labor costs include the costs of clearing land, preparing the soil, planting the seeds and collecting/handling the nuts. Additional costs that are case-specific include preventive treatments on the cashew crops against pests and other plant diseases. Trials carried out in Mozambique found that the most profitable level of pest and disease control that is also feasible for farmers gives a production of 12 kilograms per tree for a cost of US$1.3 per tree.

**Benefits**

Revenues to smallholders from cashew production will differ from country to country, and among regions in a country. In Mozambique, with an assumed yield of 3 kilograms per tree and with around 70 trees per hectare, a smallholder can expect 210 kilograms of cashews per hectare. This would translate to about US$70 (at 2011 levels) of gross margin. With use of improved production techniques, this gross margin can be effectively doubled, even when factoring the increased costs of the improved production techniques. A limiting factor to this revenue potential, however, is the size of the land holdings of the farmer. In Nigeria, one study showed that the gross margin from cashew production was as high as 36 percent of the producer sales value (Ike and Chukwuji 2005). With yields expected by year 3, the cashew plantation is shown to have a positive net income or break-even point (that is, gross income is greater than total production costs incurred) by year 6 (this does not, however, factor in any income generated by the intercropped groundnuts) (Gilleo, Jassey, and Sallah 2011). As with any other marketable commodity, the break-even point will be determined by a multitude of factors, including the current prices of inputs used, market prices at time of harvest, and the degree of pestilence or drought, that can adversely affect cashew production.

Overall, cashew production has been a major source of revenue for rural populations across many countries in Sub-Saharan Africa. As early as 2003/04, cashew farmers received US$12 million in Mozambique, US$15 million in Benin, US$22 million in Côte d’Ivoire, US$30 million in Tanzania and US$43 million in Guinea Bissau.

An additional benefit of cashews is the range of products (and subsequently income) that can be derived from various parts of the fruit: the kernel can be consumed as a nut, eaten alone or as an ingredient in sauces, cakes, and candies; cashew apple is used for juices, wine/liquor, jellies, jams, candies, cakes; Cashew Nut Shell Liquid (CNSL) is used in adhesives, paint, and other industrial materials; cashew peel is used for brake pad linings and for animal feed; and the shell can be used as fuel for wood-burning stoves and ovens. For example, in Gambia, 1 liter of locally pressed fresh cashew juice sells for around US$1.80, while the kernel sells for approximately US$7.50 per kilogram (Gilleo, Jassey, and Sallah 2011).
**Processing Cashew**

The majority of raw nuts harvested in African cashew-producing countries are shipped to India for processing and then re-exported to the United States, Europe, or elsewhere and almost all cashew nut processing is performed in India, Vietnam and Brazil. A study in Mozambique shows that only 18 percent of the value added in the final price takes place within Mozambique and a potential additional 42 percent could be captured if processing were to take place domestically (Große-Rüschkamp and Seelige 2010).

The African Cashew initiative (ACi), started in 2009, has supported the development of processing facilities in Ghana, Burkina Faso, Côte d’Ivoire and Benin. By 2012, ACi-supported companies processed 4,250 metric tons of African cashew kernels worth US$31 million which were exported to European and US markets. The new factories employ more than 4,700 workers. There is also private sector investment in processing. The ACi support helps to bring in private sector investment and the Olam Group has invested heavily in cashew processing and value chain strengthening in Africa and in 2012 opened a US$30 million processing plant in Bouake, Côte d’Ivoire (Olam 2009; Olam 2013).

A 2005 report on cashew markets listed the following major obstacles to processing of nuts in Africa (HORUS-Enterprises 2005): (i) lack of adequate supply of quality raw nuts, (ii) outdated and inefficient technology for processing, (iii) lack of financing for working capital, (iv) small domestic markets for processed cashew (Nigeria excepted), and (v) degraded port infrastructure which inhibits exports.

**Processing of Cashews at Scale**

A fully manual facility is suitable to many African cashew producing countries and is very efficient in terms of output recovery. These facilities require small capital investment, that is, US$200,000 (plus US$150,000 for a warehouse) is sufficient for facility building and US$150,000 for necessary production equipment for 1,000 metric tons per year capacity. For such a facility, US$650,000 will be needed to purchase the raw material; so, a fully manual cashew processing facility requires a total investment of about US$1.2 million. More capital is required for a semi-automated facility. The Olam investment in Côte d’Ivoire of US$30 million aims to be able process 30,000 metric tons per year.

**Recommendation Domains**

Numerous factors favor increased cashew cultivation in Sub-Saharan Africa. There is a long history of cashew production in many countries, and production rates are growing every year, as evidenced by the growth in gross tonnage of cashews produced. Cashew productivity is highest where rainfall exceeds 600 millimeters. Although there may be efforts to extend its production range into semi-arid areas, it is not likely to be competitive with dry sub-humid dryland zones where similar efforts to expand production are taking place (and dry...
sub-humid zones are nearer to major cities and ports in West Africa than are semi-arid zones).

On the production side, a key for the long-term competitiveness of dryland Africa (against growing production globally) is to raise productivity. Currently, the African Cashew initiative estimates that African cashew yields are only 25 percent of those in Brazil or Asia. Yields from existing trees can be raised through better management and yields from yet to be planted trees can be further improved through selection of the best germplasm.

In terms of processing a number of recent investments have been made at large scale in countries with large domestic production or in countries with port facilities. It will be important to monitor the success of these recent larger processing facilities to gain a better understanding of future priority investments.

**Scaling Up Issues**

A few roadblocks must be circumvented in order to truly exploit the potential for cashew production. Lack of funds and access to credit often prohibits smallholders from investing in productive practices, such as using pesticides and chemicals to safeguard their trees. In Mozambique, only about 2.5 percent of the trees are pruned regularly, 20–25 percent of the trees are sprayed and about 25 percent of farmers weed (Große-Rüschkamp and Seelige 2010). There is also restricted availability of good seeds and seedlings, either due to lack of investment in tree nurseries, or through inefficient distribution systems. As with many commodities, farmers also often face price variability—spatially and temporally for cashew which poses particular risk for farmers of perennial crops (Topper 2002).

Several issues will need to be tackled to strengthen and grow the cashew sector on the production side. Some points here are based on experiences in Mozambique (Mole 2000).

Interrelated areas that need to be addressed to obtain desired impacts in the cashew sub-sector are: (i) raising cashew yields, (ii) raising cashew prices for farmers, and (iii) lowering farmer costs of cashew production.

There is lack of access to improved technologies, particularly disease-resistant/tolerant cashew material. Where new technologies are identified, delivery mechanisms are either weak or absent. Yield increases require improved capacity in research and development of new cashew varieties with high yield potential. Development of new varieties and adaptation of others require funds for infrastructures and scientific research and training. Research experiences from other countries may well shorten the cycle of developing new and improved planting material. Tested material may only require adaptation as opposed to attempting domestically developing genuine solutions. For example, there have been recommendations to broaden the Nigerian cashew through the exploration of the Brazilian germplasm.

Better post-harvest handling and storage would have preserved the quality of the crop and prevented some of the sharp price declines. This may in turn require more investment in training and storage facilities.
Poor marketing infrastructure including transport and lack of better roads to cashew producing areas reduces farmers’ prices and profit from sales of surplus production. Despite increased effort to make market information on cashew prices available, dissemination is still far from sufficient to make farmers aware of better selling opportunities. Lack of enforceable grades and standards prevent farmers from getting a premium price from high quality nuts. Marketing infrastructure and competition must be improved if continuous price transmission from the export market demand can be expected to reach farmers in cashew producing areas.

Constrained access to credit at the onset of the cashew marketing season prevents a larger segment of the cashew industry (especially rural buyers) from participating actively in marketing, so as to improve competition in buying at the farm level.

Mango

Mango is a nutrition-rich fruit that is consumed by millions of Africans. A one cup serving (165 grams or about one-third of a mature fruit) contributes about 76 percent of vitamin C daily requirements and 25 percent of that for vitamin A. Mangoes are produced in over 90 countries worldwide. Asia accounts for approximately 77 percent of global mango production, and the Americas and Africa account for approximately 13 percent and 9 percent, respectively (FAOSTAT). Global production of mango has doubled in 30 years to around 35 million metric tons (MT) in 2009. In Sub-Saharan Africa, mangoes are the third largest group of fruits produced, behind bananas and citrus fruits. In 2009, mango production was 3 million MT, up from 2.5 million MT in 2005. African exports of mangoes grew by 69 percent during the 2001–08 period. Mango grows throughout Africa in both humid and dryland zones, as reported by the Mango Resources Information System.1

The main African mango producing country is Nigeria (790,200 MT) followed by the Arab Republic of Egypt (450,000 MT) (UNCTAD 2014). In Africa, the leading exporters are South Africa, Côte d’Ivoire, Sudan, Kenya, Egypt and Mali (Nigeria consumes almost all of its mango production). Historically Côte d’Ivoire has exported significantly higher volumes of fruit than its closest competitors on the continent, apart from South Africa. In the early 2000s, before political events broke out, the country exported 12,000 metric tons; its closest African rival was Sudan with 5,100 metric tons exported. The West African market share in Europe has been holding steady for a dozen or so years at around 10 percent, although it reached 13 percent in 2006 and 2007 (UNCTAD 2014).

Another important exporter of mango is Kenya. With almost 35,000 hectares under cultivation in 2010, mango is among the three most widely produced fruits in Kenya (along with bananas and pineapples). In 2010, Kenya produced more than 550,000 metric tons of mangoes, which reflects a 26 percent annual increase
since 2005, when the country produced only 180,000 metric tons (Government of Kenya 2012). This amount represents roughly half the production quantity in the East African countries, making Kenya a clear regional market leader. Approximately 98 percent of mangoes produced in Kenya are consumed domestically, while the remaining 2 percent are exported. Mangoes earned Kenya US$70 million in 2010 in the domestic market, up 25 percent per year from US$23 million in 2005—and US$10.1 million in export earnings, 25 percent higher than in 2009. On average, Kenyans consume 12.7 kilograms of mangoes per year, with a total estimated consumption of 474,608 metric tons in 2009. From 2006 to 2009, local consumption of mangoes grew at an annual rate of 24 percent.

Mango trees grow throughout the dry sub-humid drylands and into the semi-arid zones as well. Mali is an example where mango growing has been practiced for a long time and is now extensively found. During the 1970s, Mali was the first country in West Africa that began to focus on opportunities to export fresh mangoes. However, these exports were exclusively via air-freight, reaching a volume of between 1,000 and 1,500 tons per year, and targeted the niche market of the expensive retail shops selling tropical fruits in France (Sangho, Labaste, and Ravry 2010). Mali then led a concerted partnership to promote exports (largely to France) through a better integrated transport system from farm to port and eventually by ship to Europe. Exports grew substantially from 1,050 tons to 11,950 tons between 1993 and 2008 (Sangho, Labaste, and Ravry 2010).

**Mango Production**

One reason for the growth in mango production is the wide number of important products made from the fruit. Primary commercial mango products include fresh table fruit, dried or dehydrated ripe mango fruit and nectars and juices.

More processed mango products include mango fruit preserves in syrup, green mango pickle and powdered mango.

**Mango Production on Farms**

Mango is grown under a variety of conditions. There are differences in cultivars used, whether the germplasm is improved and grafted, the amount of fertilizer and pesticide used, and the application of other good agronomic practices. Thus the analysis of costs and benefits is highly dependent on the assumptions used. We conduct an investment analysis for a commercially oriented farmer with a cultivar in demand by the markets and with high use of inputs.

**Costs**

There are many costs associated with commercial production of mango, including fertilizer, pest and disease chemicals, and complementary irrigation. Grafting is a common practice which leads to a higher fruit to biomass ratio and leads to a wide canopy at low height which reduces labor management costs. During establishment, frequent watering during the dry months is recommended.
Planting densities are on the order of 150 per hectare or less and with lower densities intercropping can be practiced. An area of about one meter radius should be maintained weed free. Fencing or security costs may be needed depending on the local area.

Rarely do smallholder farmers apply all these “best practices” due to myriad constraints. So their costs and yields would be lower than a commercial orchard farmer.

The financial analysis draws from data in a dry sub-humid area of Mbeere, Kenya (Krain et al. 2008). It was assumed that there are 125 trees per hectare. Among the establishment costs used in the base scenario were seedlings (US$1 dollar each), fertilizer/manure and equipment and then labor for land preparation, digging and weeding. The labor/non-labor costs are about equal and in total amount to US$370 per hectare. As the fruit trees grow, costs increase for fertilizer, pesticide and harvesting. After a low cost in the second year of US$170 per hectare, they grow to US$632 in years 3 and 4, US$1,050 in years 5–8 and then US$1,382 thereafter. These are considerable, but are reasonable on a “per-tree” basis (US$11 per tree in full production years).

In terms of production, the analysis assumes that each tree will bear 300 fruits at full production which is below what commercial farmers would expect to obtain. This is phased in from year 3 in the case of high-quality grafted seedlings increasing to juvenile production in years 5–8, and then full production in years 9–20. The price per fruit used in the base scenario is a typical farmgate price of US$0.05.

Scenario analyses examined how changes in discount rates, productivity per tree and prices altered the results.

Table 3.4 shows results from financial analyses of mango growing under a number of different assumptions. Although mango growing is profitable in all cases, the NPV is relatively low under the assumption of 300 fruits per tree and a 20 percent discount rate. Moreover, the benefit cost-ratios are not much greater than 1 in all the scenarios using 300 fruits per tree. The ability to grow (and sell) 350 fruits instead of 300 per tree greatly increases the NPV and benefit–cost ratio (BCR) of this system. This also increases the internal rate of return from 24 percent to 37 percent. Another important variable is the breakeven year. In the most conservative scenario of a 20 percent discount rate and 300 fruits per tree, the breakeven point does not occur until the 14th year. On the other hand, at 350 fruits per tree, the breakeven point occurs at years 6 or 7 depending on the discount rate. At an assumption of 20 percent discount rate, the NPV falls below zero if production drops below 256 fruits per tree. So maintaining high production is key in this particular high input system.

**Social Costs and Benefits**
Mango trees do not pose significant negative or positive externalities. They do have a large and dense canopy, but the effect of that is in situ, and therefore results in private opportunity costs. They do not offer any particular resilience
### Table 3.4 Private Economic Returns from Mango Production in Kenya

<table>
<thead>
<tr>
<th></th>
<th>300 fruits per tree; 125 trees per ha</th>
<th>350 fruits per tree; 125 trees per ha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NPV</strong></td>
<td></td>
<td></td>
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<tr>
<td>10% discount rate</td>
<td>1,464.69</td>
<td>3,184.99</td>
</tr>
<tr>
<td>15% discount rate</td>
<td>673.58</td>
<td>1,819.28</td>
</tr>
<tr>
<td>20% discount rate</td>
<td>228.89</td>
<td>1,034.25</td>
</tr>
<tr>
<td><strong>BCR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% discount rate</td>
<td>1.17</td>
<td>1.36</td>
</tr>
<tr>
<td>15% discount rate</td>
<td>1.11</td>
<td>1.29</td>
</tr>
<tr>
<td>20% discount rate</td>
<td>1.05</td>
<td>1.22</td>
</tr>
</tbody>
</table>

advantages over other trees apart from its harvest calendar. In the Sahelian semi-arid and dry sub-humid zone the major harvest period for mango is at the end of the dry season (in May) when other foods are scarce. Similarly, in Kenya, all mango varieties are ready for harvest in the December to March period which is in advance of the major rainy season.

Although there are other fruits and foods to invest in, mango is the most accessible source of high amounts of vitamin C for a very large number of rural Africans. Its national and global demand is high and growing, thus offering stable income opportunities as population continues to grow. Data from Kenya show that production and exports of mango was growing at more than 20 percent per year from 2005 to 2010 (Government of Kenya 2012).

### Recommendations Domains

There are no reliable publicly available data on current or projected domestic demand–supply comparisons for mango, so it is not possible to identify countries where mango production investment may be particularly attractive. On the other hand, there are inherent advantages for dryland countries with seaports if export markets are within reach by sea freight. This is the case for Kenya, for example, as 95 percent of its mango exports are to the Middle East. But since mango is perishable, sea freight involves some risk and transportation must be very efficient. In addition to fresh fruit exports, the fruit juice market is huge and growing rapidly (more than US$11 billion in trade value in 2007). In the medium to long term, provision of juice concentrates could become a huge opportunity and this would again favor coastal countries.

### Opportunities for Investment

Investments in provision of high quality germplasm of varieties the markets demand, in improved agronomic practices and in post-harvest handling are key areas for attention on the production side.

*Limited access to good quality planting materials.* At the farm level, key constraints faced by farmers are the lack of clean planting material of varieties/cultivars...
vars that are in demand by primary consumers or processors. There is a general-
ized shortage of scions and grafted seedlings. Hence, farmers tend to use inferior,
low yielding seedlings from locally available trees. Whereas grafted trees begin to
bear fruit within three to four years, ungrafted trees will take at least five years
to bear fruit, depending on the growing conditions. Improvements in this area
will require the acquisition/collection and production of high-quality germ-
plasm. In Kenya, the private sector is involved in this area, but in many countries,
the public sector may need to catalyze a high-quality germplasm supply sector
by producing “mother” blocks that can be the source of multiplication value add-
ing by either private or public sectors. Where private sector firms are involved,
the public sector will need to provide oversight to assure quality and prevent
counterfeiting from becoming prevalent.

Poor orchard management. Few farmers have knowledge on improved produc-
tion practices such as grafting, and there is poor use of fertilizers and pesticides.
Except for large or commercial farms, mango trees are normally scattered around
the gardens, ranging from 2 to 10 trees per household. Extension systems have
generally neglected tree management as part of their main messages to farmers
and thus there is need to improve the capacity of extension agents in a range of
tree management practices (notably in fruits and timber).

Post-harvest losses. Farmers suffer from poor post-harvest handling tech-
niques, leading to significant losses, which affect returns to producers and
traders. At the marketing stage, a major constraint is the poorly developed
transport infrastructure, such as the bad road conditions that serve production
areas which further contribute to post-harvest losses and a deterioration of
quality leading to low selling prices. Farmers often lack the necessary informa-
tion on alternative marketing possibilities and on alternative product uses,
such as drying, and other options for value addition. Traders themselves often
suffer from poor access to credit, which makes it difficult for them to finance
their operations.

Inappropriate varieties for sea freight, inadequate sea freight facilities and high
air freight costs are among the major constraints to export growth. Moreover, the
need to comply with the EUREGAP and traceability standards, which are neces-
sary to enter the European Commission market, constitute a further challenge.
African exporters themselves often suffer from price instability in international
markets and from stiff competition from other countries like India, Pakistan,
Brazil, Mexico and Costa Rica. These competitors offer higher quality varieties
at lower prices, due mainly to lower shipping costs.

In the area of physical infrastructure, particular emphasis should be given to
storage facilities and to transportation. Storage is essential for extending the con-
sumption period of fruits, regulating their supply to the market and also for
transportation to long distances. Concerning institutional infrastructures, the
development of adequate credit facilities and other services required by the sup-
ply chain and setting up collective farmers’ bodies, responsible for marketing and
for the interaction with other stakeholders in the chain, must be examined.
Scaling Up Issues

Mango production for subsistence is already widespread in the drylands, albeit with low productivity. The big challenges are related to scaling up a commercial mango sector. Existing mango production is characterized by scattered production of a few trees per farm and with multiple varieties grown even in the same village. And of course quality will differ from farmer to farmer. This makes it costly for a buyer to find a large quantity of high-quality fruits of the same variety within a small area. Some forms of collective action at the producer level—for example, for quality control—would reduce the costs to the buyer and improve marketing prospects for producers.

Pest and disease management is critical, as fruit production can be decimated by outbreaks of pests or diseases. Pests and diseases can be managed by individual farmers but are more effectively managed in landscapes by concerted efforts, combining the use of chemicals and biological control methods.

It is obvious that African farmers can increase mango production further, given the high rates of past growth. What will drive further increases are on the market side. There is expected to be moderate demand growth in fresh fruit sales due to population growth and urbanization. But these opportunities are limited by seasonality of harvests—that is, there is considerable unmet mango demand during non-harvest periods. Growth in production could accelerate if new products such as juice concentrates can be developed. Juice concentrates have longer shelf life and thus a much larger harvest of mango, even if in a confined harvest period, could serve an annual demand.

Timber and Pole Production

Definition and Technical Potential

Production for wood can involve a number of ultimate uses: fuelwood, construction poles, utility poles, fencing, pulp, plywood, and timber, which in turn is used for a variety of purposes such as buildings and furniture.

The technical potential for poles and timber in the drylands is varied with higher potential in the dry sub-humid zone and little potential in the arid zone. Still, strictly in technical terms, productivity of timber trees is higher yet in the sub-humid and humid zones, leading to shorter rotations and breakeven points as well as higher net present values. The advantages of the drier zones lie more with opportunity costs and land availability. In more humid zones, farmers have a choice among a large number of enterprises and may find enterprises such as tea production, horticulture or dairy farming to offer better risk and discount rate adjusted returns than timber growing. In the drylands, there are fewer viable enterprises and most of those come with high risk—for example, rainfed cereal production. Timber growing is also labor saving and land using compared to other enterprises, which is well suited to the less densely populated drier zones. So in that sense, timber can be competitive in the drylands and the drylands in turn can be a viable supplier of timber.
There are almost no data available on production of wood in Africa, apart from exports which is largely hardwoods harvested from forests. So for this case study, we move directly to the micro analysis.

**Costs of Wood Production**

The main costs to a farmer growing timber or poles are establishment and maintenance costs. Key establishment costs are:

1. Costs of germplasm when planting trees, which is likely to be the case for timber and poles. The likely type of germplasm for timber and poles is a seedling. Some clonal varieties are available for *Eucalyptus camaldulensis* (which is suitable for drylands) but not for other dryland species. Quality of germplasm is critical for buyers of seedlings as the net benefits depend greatly on survival, growth rates and traits. Farmers are thus willing to pay a premium for assured high quality.

2. Protection of trees—either in the form of micro protection of individual trees or protection of larger areas mainly using wood-based barriers or fences. There could also possibly be some labor costs for guarding the trees against cutting or browsing.

3. Watering of trees—farmers may need to water timber or pole trees especially during the first or second years. Farmers may also invest in micro water catchments around trees to channel water to them.

After establishment, there may be additional maintenance costs of:

1. Weeding—this will be important for the young planted trees to prevent competition for water.

2. Pruning and thinning of trees—this will be a required task for producing wood of commercial value. Pruning is done to keep growth straight and upward while thinning is practiced to retain the better performing individuals and to allow them access to more light and water resources as they mature.

3. Cutting of trees for timber or poles and sawing of trees into logs/boards. Poles are harvested with a single cut and pruning of top branches. Timber trees can be further processed into logs or sawnboards. Few farmers have the competence or equipment to do this and will hire sawyers to do the work for them. Costs could be paid either directly to the sawyer, for the labor and equipment, or what is common is that the tree grower and sawyer will share the revenues so that the farmer does not actually make a payment to the sawyer.

Information on actual costs was taken from studies on dryland timber growing in Kenya, in particular for *Melia volkensii*, a good timber species, and *Eucalyptus camaldulensis*, a good pole producing tree. Studies found establishment costs to vary from US$600 to US$1,200 per hectare with the higher figure also including additional land preparation and fencing costs (Kamondo et al. 2004; Oballa et al. 2010).
Data on labor amounts for specific tasks such as watering, weeding, pruning and thinning on smallholder farms were not found, but estimates of total annual maintenance costs were given as US$200 per hectare per year, excluding the establishment and harvesting years (Oballa et al. 2010). This is based on a per day labor cost of US$1.25.

A common practice in East Africa is for a sharing of proceeds arrangement to be made where a sawyer cum buyer will provide sawing services for a share of the revenues from the tree. Because there exist data on market values for poles and timber as well as some common sharing arrangements, the benefit value for the farmer net of the harvest costs can be calculated (Carsan and Holding 2006; Hulusjö 2013).

The timber and pole output sector is commercialized throughout Africa with private sawyers, buyers, processors and transporters active. So on this part of the value chain, the most important public costs are the usual as for almost all commodities—to improve infrastructure in order to reduce transport costs. On the input side, productivity and profits are very dependent on high-quality tree germplasm and governments have a role to play. The input sector is highly private oriented in many parts of the drylands, such as Kenya but there is still need for the public sector to put systems in place so that high-quality tree germplasm is available in the country and to put checks in place so that farmers are assured of the qualities purported by retailers.

Alternatives to Farm Timber Production

For African nations, the costs of not producing sufficient timber and poles would be the importation of wood or perhaps substitute materials for similar uses (for example, metal instead of wooden utility poles). This would certainly result in higher prices and lower employment assuming that both of those options are met through imports.

Within a country, wood supplies may be able to be supplied through more humid areas (for example, Kenya, Ethiopia) instead of drylands or through government plantations rather than on farms. Taking Kenya as an example, woodlots are a popular investment for farmers in certain areas of the country, notably in the western highlands, while boundary planting with timber species is popular in the central highlands. In both cases, the trees are commercialized for a variety of purposes, including for the pulp and paper industry. The Government of Kenya banned logging from gazetted forests in 1999 and subsequently began to invest in rejuvenating forest plantations. Therefore, in the future, there will be additional sources of wood coming into the market. Generally in Africa, there has been a trend towards increased provision of wood from farms and this is expected to continue into the future with continued conversion of forests and woodlands and a weak public plantation sector.

There are tradeoffs in producing timber and poles in drylands, should they prove to be profitable. The chief concern would be in terms of use of water. Already, many countries have issued bans or guidelines for growing Eucalyptus
species and in particular warn against growing them near important water sources for other important needs. In terms of competition with crops, calculations can be made in terms of returns per unit of water to determine whether planting trees makes sense from a water efficiency point of view.

**Benefits**

The main benefits are timber and poles. The types of trees that are grown primarily for these functions will also produce some fuelwood, mainly through pruned branches and some thinned out poor performers. There may also be some side benefits such as medicines or fodders, but these trees serve primarily wood production purposes. Hence the cost-benefit analysis values only these wood outputs to constitute to the benefit.

In the example from Kenya, benefits are derived either from pole production, assuming an 8-year rotation, or timber production, assuming a 10-year rotation (Kamondo et al. 2004; Oballa et al. 2010). Key variables are the prices received and the final densities of trees per hectare. Normally, densities are considerably higher (for example, twice as high) for pole production as for timber production. The base assumption is for 1,000 trees per hectare for timber and 2,000 per hectare for poles. However, these are varied in alternative scenarios. The price of an 8-year pole was assumed to be US$10 in the base case and the base share between buyer and farmer was 50–50. Thus the revenue for a farmer in the base scenario was US$5 × 1,000 = US$5,000 every eight years.

In the case of timber, the value will be higher than that for a pole, if it is a species in demand for higher value final products. If the timber is converted into sawn logs or boards, its value could be three to four times greater than the standing tree. Therefore, sawyers are often hired to create this additional value. However, there is about a 30 percent loss of standing volume as these methods are often crude with poor equipment. So the base case scenario is one where the value of a single tree’s sawn wood is US$28, representing a price of US$40 per tree less 30 percent wastage. The farmer receives half the price at a 50–50 share and so his revenue in the base case is US$14 × 1,000 or US$14,000 per hectare every 10 years.

As with all trees there may be some benefits of soil conservation, notably if the trees are planted on sloping land. There will also be shade and micro-climate effects, but if the trees are planted apart from crops, those effects may not translate into increased crop benefits, unlike the case with FMNR.

The main positive environmental benefit from timber and pole planting, however, is carbon sequestration. In the dry sub-humid zone, trees can add on about 20 kilograms of wood biomass per year or 10 kilograms of carbon. In the example of growing poles, that would be up to 20 tons of carbon per hectare per year. This is not captured in the model of private costs and benefits as payment mechanisms for carbon sequestration are not well developed.

Finally, in discussing the benefits of TBS, it will be important to refer to the concept of resilience.
Timber and pole planting is not likely to be able to reduce exposure to shocks such as climate change and variability, pest incidence, winds, price changes and the like, even if practiced at scale. This is because the scale of timber and pole planting will be limited by overall demand for such products. Furthermore, timber and pole planting will not be able to reduce sensitivity to shocks as much as FMNR is able to, since it produces a smaller range of products and services. However, timber and pole planting can contribute significantly to coping strategies. These wood products can be harvested and sold for income anytime during the year.

**Returns to Investment**

A model was constructed to analyze costs and benefit streams per hectare over a time frame ranging from 20 to 30 years. Two products were analyzed: poles and timber and the base scenarios were based on production in the dry sub-humid environment of Kenya. The base case also assumed an 8-year rotation for poles and a 10-year rotation for timber. From this base, different scenarios were run on rotation period, densities of harvested trees per hectare, prices of the wood product (including the share to the farmer), costs of establishment and discount rates.

Using the above assumptions, table 3.5 shows the net present value and benefit–cost ratio for the different combinations of discount rates and time periods for poles and timber production.

Starting with poles, it can be seen that the profitability is sensitive to the density of trees planted. This is because of the relatively low price of poles as compared to timber, yet the costs of establishment and maintenance are similar. Thus, at a density of 1,000 trees per hectare and a retail price of US$10 per tree (with the farmer receiving US$5), pole production is profitable at a 10 percent discount rate but not higher ones. However, at a density of 2,000 trees per hectare, growing poles is very profitable at various prices and discount rates. The benefit–cost ratio is as high as 2.32 at a 10 percent discount rate.

At a density of 1,000 trees per hectare and an 8-year rotation, growing poles appears to be a risky proposition in the drylands. The density needs to be at least 1,400 trees per hectare to be profitable at a price of US$10 and a discount rate of 20 percent. At a 2,000 trees per hectare density, there is greater scope for profits even under price risks. Retail pole prices can drop to US$4.30 and the NPV is still positive.

Two rotations of timber growing with 1,000 trees per hectare is similar in NPV to three rotations of poles at a density of 2,000 trees per hectare. The internal rates of return are also similar in the two scenarios (0.28 for poles @ 2,000 and 0.25 for timber @ 1,000). The benefit–cost ratios range from 1.34 to 2.51 for discount rates of 0.2 and 0.1, respectively. Building from the base scenario of US$40 per tree and 70 percent usage rate, timber growing is sensitive to rotation period. At a 20 percent discount rate, it is still profitable in an 11-year rotation (but not 12); at a 10 percent discount rate, timber growing is still profitable in a 17-year rotation. This is why growing timber in the more arid drylands, where longer rotations are necessary to produce similar quality products, is less attractive.
Table 3.5  Private Economic Returns from Pole and Timber Production in Kenya
US$/hectare

<table>
<thead>
<tr>
<th></th>
<th>Poles in Kenya</th>
<th>Timber in Kenya</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 rotations,</td>
<td>3 rotations,</td>
</tr>
<tr>
<td></td>
<td>density of 2,000</td>
<td>density of 1,000</td>
</tr>
<tr>
<td></td>
<td>trees/ha</td>
<td>trees/ha</td>
</tr>
<tr>
<td>10% discount rate</td>
<td>4,916.94</td>
<td>595.80</td>
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<td>15% discount rate</td>
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</tr>
<tr>
<td>20% discount rate</td>
<td>1.34</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Recommendation Domains
The recommendation domain for timber and pole growing is largely for the dry sub-humid zone. Since transportation costs are high and demand for construction wood is ubiquitous, there is need for access to poles in all dryland zones. However, such wood is most likely to be collected and not paid for and farmers will collect this from naturally growing trees. By contrast, the dry sub-humid areas have the potential to produce higher quality timber and poles for sale to rural-based institutions and urban markets.

The growing of poles and timber compares favorably against many agricultural commodities in terms of annualized returns per hectare. A key issue for recommendation domains is however, the long delay before realizing income (at least eight years in dry environments). This will prevent large-scale investments by any individual farmer and can dissuade farmers with limited land resources from the practice altogether.

Another key issue is that of limited market opportunities for timber and poles. Such products from dryland farms are likely to serve only the domestic market. In some dryland countries, there are also sub-humid or humid zones where much tree planting occurs and which is often closer to the capital cities (this would include Ghana, Nigeria, Ethiopia, and Kenya, for example). In such circumstances, further study on the competitiveness of dryland timber and pole production is needed. On the other hand, in countries such as Mali, Burkina Faso and Niger, the dry sub-humid zone offers the highest potential for timber and pole production from both a technical and market access perspective.

Scaling Up Issues
Timber and pole production that meets demands for quality and is competitive with imports or substitutes requires a functioning commercial sector on the
input and output side. On the input side, high-quality seed suited to the drylands needs to be produced and transformed into viable seedlings through private nursery operators. For upscaling at a significant scale, financing that can spread the farmer costs of these long-term investments over multiple years would facilitate the process considerably. Private buyers of the timber could be one source of finance, as was pivotal in the scaling up of smallholder timber growing in northwest India.

Needless to say, market efficiency plays a huge role in timber and pole growing. As there are no perishability concerns for wood, efficiency is in processing (which must include an element on farm), handling and transportation from farm to wholesaler. The basic needs in road development apply here but perhaps with the added needs of large trucks capable of transporting heavy loads. In addition, the transportation of wood products is well known to be subjected to many other charges, some legal and some extra-legal. All of these transactions costs work against the development of a domestic wood supply and value adding sector.

Note

This section summarizes the recommendations for scaling-up the most promising tree-based production systems (TBS) that were covered in the above sections. They are summarized for each dryland zone.

Before turning to the zonal recommendations, a more general recommendation domain for agroforestry in the drylands has been developed by the World Resources Institute (map 4.1). This shows that there is a vast area of cropland between 400 millimeters and 1,000 millimeters of annual rainfall where agroforestry is suitable. This includes large areas of the West Africa Sahel, the horn of East Africa and Southern Africa. As we note below, the key recommended agroforestry practice applicable in each of these zones is farmer-managed natural regeneration. This may be considered as a foundational practice for use on all farms in the zone, as it will complement all other improved farming practices and cropping and livestock systems in the zone.

The second African Drylands Week, convened by the Africa Union in N’Djamena, Chad from August 25 to 29, 2014, reviewed the evidence of the massive scale of transformations in land regeneration that are occurring in the Sahel, and in parts of East and Southern Africa, by applying the principles of FMNR on croplands, Assisted Natural Regeneration (ANR) in forest and grazing lands (particularly in Ethiopia), and through other forms of EverGreen Agriculture. The conference declaration noted that the upscaling of these practices can contribute substantively toward meeting the commitment of the African Heads of State in Malabo to ensure that 30 percent more households in Africa are resilient to climate change-related risks (Malabo Decision, June 2014), and to achieving the 25by25 vision within the context of the African Climate-Smart Agriculture (CSA) Alliance and the Comprehensive Africa Agriculture Development Programme (CAADP) Climate Change Programme, which is aiming to achieve 25 million farmers practicing CSA by 2025.
The conference therefore acted to “RECOMMEND AND PROPOSE that the drylands development community, through the African Union, and all collaborating and supporting organizations, commit seriously to achieving the goal of enabling EVERY farm family and EVERY village across the drylands of Africa to be practicing FMNR and ANR by the year 2025.”

The AU is also currently developing a strategy to end hunger in Africa by 2025 that builds on the Malabo Declaration. In this context, a target is being developed for the scaling-up of fertilizer tree technologies (FTTs) to contribute to a doubling of food production by 2025. This target will include a range of FTTs in addition to FMNR that encompasses conservation agriculture with trees, and other nitrogen-fixing tree systems, such as those deployed in the Malawi National Agroforestry Food Security Programme, the Zambian Conservation Farming Programme, and the Ethiopian National Faidherbia Programme.
Arid Zone

The arid zone is dominated by pastoral production systems. These include extensive grasslands with few trees currently in some part of the zone, while in others the landscape is dominated by shrubland or scrub. In the arid zone, the successful establishment of trees is very difficult unless there is access to irrigation. In addition to the harsh conditions, making tree planting a risky and costly proposition in this zone, the migratory nature of the populations and lack of individual tenure on land means that incentives to plant and manage trees are low.

Recommendation 1: Deploy assisted natural regeneration of trees and shrubs in pastoral arid conditions as a foundational practice for improving livestock production with enhanced ecosystems services, including carbon sequestration.

Recommendations for advancing resilience for the vast majority of pastoral arid lands in relation to TBS revolve around the role of trees and shrubs in the improved management of grazing or browsing lands for enhanced fodder biomass production and higher and more resilient livestock productivity, along with the associated benefits derived from the products of specific tree species that are adapted to these conditions. As a foundational practice, ANR would be recommended for consideration to be deployed in the regeneration of all types of improved grazing systems in the zone.

Creating the conditions for tree regeneration in the arid zone is the key intervention. Assisted natural regeneration is referred to as a foundational practice as it is the practice that must first be considered, and upon which other specific TBS practices may build. Effective tree regeneration is a function of expanding the deployment of areas of limited or complete exclosure or enclosures (corraling of animals within an area to concentrate manure) of certain patches of a landscape for a limited period of time to allow useful tree vegetation to be established. The amount of land in a given exclosure would depend critically on herd to land ratios, and amount of land that could temporarily be taken out of grazing, considering local conditions.

Where livestock pressure on the land is high, the areas of exclosure would need to be kept modest in size, and put back into grazing after a few years as soon as the tree vegetation in a given area had been reestablished. The successful experiences with the deployment of the exclosure principle in the rapid regeneration of healthy woodland-savannas in Ethiopia, in the conservancies in Kenya, and in the ngiri systems in Tanzania (discussed above) indicate that there is enormous potential for their further expansion in these countries, and their appropriate introduction and/or upscaling in the arid portions of other countries within the zone. These successes have also emphasized the need for dialogue among all land users and the importance of formal agreements to reduce the risk of conflicts among them.

Recommendation 2: Invest in the assisted natural regeneration of high-value commercial tree species that are adapted to arid zone conditions. The key species of focus are Gum Arabic, myrrh, and frankincense.
In those parts of the zone where the collection of Gum Arabic and myrrh are already important income-generating activities at the local level, but also to a limited extent elsewhere, further investments in the deployment of strategic exclosure management systems in particular sites identified as high potential for these commercial trees, and improved tree management, will be an important additional dimension. Careful attention to the enabling conditions for the expansion of these valuable commercial species will be necessary in the areas where these species are currently adapted to manage the trade-offs and potential conflicts that might arise.

Countries that currently have large expanses of *A. senegal* (for Gum Arabic) include Burkina Faso, Ethiopia, Mali, Nigeria, Senegal and Sudan. Sudan has the largest plantations of *A. senegal*, with well over 100,000 hectares (Chamshama 2011). World demand for Gum Arabic in 2020 is projected to expand in the short and long term.

Other commercial gum resins of high economic value include myrrh, frankincense (gum olibanum) and hagar. Producer countries for these commodities in Africa include Somalia, Kenya and Ethiopia. The market demand for these commodities is also expanding.

Rainfed and irrigated crop farming is expanding in the arid pastoral system zone. In the rainfed zone, where crop farming is exceptionally vulnerable to drought, farmer-managed natural regeneration should be vigorously upscaled as a means to buffer and diversify the production systems to increase and stabilize crop yields. The experience with FMNR in the northern parts of the Maradi and Zinder regions of Niger are particularly cogent models for the extension of FMNR in analogous areas of many other countries.

**Recommendation 3:** In the irrigated area of the arid zone, including the oases agro-ecosystems, high-value fruit tree production is recommended as an attractive investment opportunity in situations where transportation and market linkages are present.

Species such as the date palm and mangoes may be attractive opportunities in these situations.

**Recommendation 4:** Invest in the development of sustainable charcoal and fuel-wood management systems in arid zone areas where unsustainable production systems are currently degrading the future production potential.

This will require vigorous policy reform combined with practical management systems that build upon new knowledge of the natural regeneration capacity of the dry woodlands in arid situations.

**Semi-Arid Zone**

The semi-arid zone is dominated by agropastoralism with rainfed cropping systems based on millets and sorghum.

**Recommendation 1:** Farmer-managed natural regeneration of useful trees on the agricultural land is recommended as a foundational practice throughout the semi-arid zone.
The multiple benefits of FMNR in climate buffering, enterprise diversification, livelihood intensification, and asset building have been described above in detail. The verified experiences of farmers on a wide scale in Niger, Mali, Senegal, and elsewhere indicate that investments in adapting and scaling-up this simple set of practices could lead to rapid change and extensive impacts universally in all countries with land area in this zone. It is referred to as a foundational practice as it would provide for the majority of trees on farms in semi-arid lands in all regions. It should thus be considered as an essential component of any TBS program.

The scaling-up process for FMNR can be embedded into a range of sustainable land management and improved crop management project investments across the zone.

Recommendation 2: While natural regeneration is the key broad-based foundational recommendation, there are some important opportunities for planting high-value trees for nutrition and income generation.

These would largely be high-value fruit and vegetable trees that would justify the establishment costs (for example, in watering seedlings). Locally, there are a range of such options, such as baobab, parkia, and moringa, while mango is broadly adapted and currently grown, and widely recommended.

Shea production is more amenable to the dry sub-humid zone, but also occurs in some parts of the semi-arid zone, such as in Mali and Burkina Faso, and Uganda. Local and international markets for shea have expanded rapidly in recent decades. Investments in the protected regeneration of shea trees in the farming systems, and in improving the processing and marketing of shea products, are needed to expand sustainable production and processing systems to enhance the income-generation potential of the commodity.

Recommendation 3: There is widespread potential for the regeneration of the dry forests and community woodlands in this zone by deploying the practices of assisted natural regeneration through partial or complete exclosure on a temporary basis.

These practices require a landscape approach and the nurturing of community-based environmental management institutions. The successful experiences with the deployment of the exclosure principle in the rapid regeneration of healthy woodland-savannas on 15 million hectares in Ethiopia, the conservancies in Kenya, and the ngitili systems in Tanzania indicate that there is major potential for their further expansion in these countries, and their appropriate introduction in the portions of the other countries within the semi-arid zone.

Recommendation 4: Invest in the development of sustainable charcoal and fuelwood production systems in the semi-arid zone areas where unsustainable production systems are currently degrading the future production potential.

This will require vigorous policy reform combined with practical management systems building upon new knowledge of the natural regeneration capacity of dry woodlands in arid situations.
Charcoal production and marketing to the rapidly expanding urban populations in this zone is a growing industry and it will continue to be a major source of energy for many decades into the future. Most major cities have seen their charcoal supplies decline in their surrounding hinterlands and are now obtaining their supplies from hundreds of kilometers away. Comprehensive attention to the evolution of sustainable charcoal systems is becoming an urgent matter in these situations.

**Dry Sub-Humid Zone**

Agriculture in the dry sub-humid zone is dominated by cereal production, particularly maize-mixed farming systems. In the northern reaches of this zone across the continent, shea is a major complementary TBS and is a major FMNR system.

**Recommendation 1:** A foundational TBS recommendation for this zone is FMNR with useful trees, and deserves to be emphasized in conjunction with virtually all other agricultural development initiatives.

This recommendation is similar to those for the arid and semi-arid zones. Regeneration will continue to be a critical practice to generate large numbers of trees in all drylands.

**Recommendation 2:** Supplement FMNR investments with the accelerated cultivation of planted trees in the croplands and field boundaries in all sub-humid farming systems.

The planting of trees is common in this zone. This is more technically feasible in this zone, and the growth rate of trees is also faster, reducing the time to deriving benefits from the investment. Although the number of trees regenerated on farms may exceed those planted, the value of production from high-value planted trees can be higher than that from regenerated ones.

Continuous crop production has become the norm in most parts of this zone, and as a consequence the maintenance of soil fertility has become a critical challenge. Scaling-up the incorporation of fertilizer-fodder-fuelwood-fiber trees into croplands is universally recommended across the zone to enable crop yields to be increased sustainably, while enabling farm households to further diversify their sources of fodder and fuelwood, and build their asset base. Site-specific management systems will vary depending on local conditions. The appropriate species, densities, and pruning regimes will vary and should be given more research attention. A key opportunity here is to plant fast-growing N-fixing fertilizer trees in a grid pattern throughout the cereal crop fields, and to pollard the trees for sustained production of the cereal crops.

**Recommendation 3:** There are major investment opportunities for the widespread expansion of high-value trees for nutrition and income generation at small and medium scale.

Key options include shea and cashew production for both local and international markets.
Improving the processing and marketing of shea products would be a primary investment direction, particularly in those countries where the commercialization of shea markets is rapidly developing, including southern Mali, Burkina Faso, and northern Uganda. In countries such as Nigeria and others in the West Africa dry sub-humid zone where the processing of shea and/or the exportation channels are under-developed, there is an urgent need to initiate development of processing and marketing systems.

Cashew is a significant tree commodity in a number of countries in the dry sub-humid zone. There is major potential for investment in rebuilding and expanding cashew production systems in these countries.

Numerous species identified in this report have been found to contribute significant income to farmers in selected locations. Species that produce products for which there is strong urban demand, such as fruits, poles and timber, have greater potential for scaling up.

Recommendation 4: Invest in the regeneration and improved management of the forests and community woodlands in the sub-humid drylands zone by deploying the practices of assisted natural regeneration, and also encourage the expansion of smallholder timber production.

Institutional innovations that enable successful management of community forests are a key investment direction for the dry sub-humid zone, where assisted natural regeneration is also a preferred production practice for their sustainable regeneration. Successful models discussed above provide a basis for these investments.

Smallholder timber production on farm is increasingly popular in this zone. This may involve the production of species such as eucalyptus that are planted in woodlots and sold for timber or poles. Alternatively, it may involve the cultivation of timber species in crop fields as an intercrop with food crops, using tree species that can be managed compatibly with crops, such as *Grevillea robusta*.

**Note**

1. See: [http://rea.au.int/en/content/second-africa-dry-land-week-n%E2%80%99djamena-chad](http://rea.au.int/en/content/second-africa-dry-land-week-n%E2%80%99djamena-chad)
The factors for scaling up of tree-based production systems (TBS) below cover aspects of production, value chain development and policies/institutions, in synchrony with the list of priority TBS above. Each factor, apart from the factor of germplasm supply, is equally relevant whether trees are established through regeneration or through planting.

### Changing Attitudes/Mindsets toward the Integration of Trees in Agriculture

The benefits of trees have been well-appreciated by generations of farmers. However, there remain some obstacles toward the better integration of trees on farm, for which there is increasing need given the continued conversion of woodlands into agriculture in the drylands. First, there is renewed interest from agricultural programs to promote conventional crop agronomy—good seeds, mineral fertilizer and having “clean” fields using animal traction—where mixing trees with crops has not been typically recommended due to the perception that they compete with crops. This, of course, ignores the positive synergies that trees can have with crops and it also ignores the fact that some trees can provide products of higher unit area value than crops. Second, foresters in most countries continue to implement policies which have adverse incentives on farmers to grow trees on their land. The most common one is the protection of certain indigenous species meaning that they cannot be cut or sold without license and fines are issued for violations. This legacy of being “forest policemen” instead of tree extensionists continues today.

The conventional mindset permeates the formulation of development programs by governments, and even some NGOs, who then neglect to include trees as part of agricultural development programs, or even discourage the practice. Therefore, this issue is mostly about changing attitudes among organizations that interface with farmers. There is as well the need to alter the mindsets of higher level policy
makers. Many see trees serving only environmental purposes and they fail to recognize the large income-generating roles that trees can play in sustainable agricultural intensification, increased crop production, and livelihood improvement.

Farmers themselves are generally very open and receptive to managing trees on their farms, as they all tend to use trees as part of their farming system. One key issue here relates to attitudes toward women’s rights to trees, which are not very progressive in many communities. If both women and men were able to influence tree management decisions, trees could play a more beneficial role on farms. Lastly, there are other resource users whose main objectives may come into conflict with those managing trees. These include herders, bushmeat collectors, and charcoal burners, whose actions regarding grazing/browsing, fire-setting and felling can conflict with successful tree regeneration and management.

Actions:

1. Expand the documentation and dissemination of the benefits of TBS, notably systems that are integrated with crops and livestock
2. Increase the documentation and dissemination of the costs associated with onerous forestry regulations
3. Intensify advocacy for and implementation of pilots of new approaches for agriculture and forestry that can be jointly monitored
4. Deepen the technical support to the designers of all agricultural development programs to be able to better include TBS among their interventions

**Spreading Awareness and Knowledge of Improved or New Practices**

While farmers have been managing trees for generations, in the drylands more than anywhere else, they are accustomed to the performance of native species which have locally regenerated without significant management. This means that most farmers are unaware of the potential improvement in the productivity of native trees that can be achieved under improved management. They need to be exposed to different propagation techniques, improved tree germplasm, and better management techniques for which growth and productivity can be significantly greater than what is observed in the typical landscape.

There are in addition a range of management options available for soil fertility regeneration, fodders, fruits and timber in the semi-arid and dry sub-humid zones that relatively few farmers are aware of. Extensionists and development organizations (including farmer organizations) themselves are poorly trained in these new techniques, and building this technical capacity should be a focal emphasis of a scaling up program.

Actions:

1. Expand the documentation of promising TBS options and their dissemination for awareness creation via many different media
2. Regionally, intensify the promotion of TBS in large development initiatives, like the Great Green Wall of the Sahel
3. Broaden the technical training of agricultural and forestry extension agents and development staff to cover TBS
4. Locally, promote TBS through demonstrations on farmers’ fields
5. Promote field visits for opinion leaders and farmer leaders to successful TBS practices on farms

**Improving Local Landscape Management—Especially Grazing Management, and Fire Control**

In the drylands, a number of resource users apart from farmers have effects on the success of tree-based systems, both on farms and in the woodlands. These include herders, charcoal makers and mammal and rodent hunters. Trees and shrubs are essential sources of feed during the long period of time when there is no fresh pasture or crop stover. While browsing can often be a mutual benefit to the herder and tree owner, it is also recognized by many farmers as a key threat to natural regeneration.

Charcoal makers do negotiate the use of trees, but not all stakeholders are involved in the final decisions and thus the resulting felling of trees may not be in the community’s interest. Hunters use fire as an aid for catching rodents and small mammals with the externality of destroying some vegetation. These practices provide many benefits and therefore will need to continue. But more progress can be made to protect mature or young trees temporarily from grazing (exclosures) or to create more incentives for herders to manage livestock away from young fragile trees. This requires investments in dialogues on landscape management among different interest groups.

**Actions:**

1. Expand support for landscape stakeholder meetings to diagnose problems and jointly identify solutions at the landscape level that can benefit communities
2. Disseminate successful landscape management experiences and models
3. Promote the creation or strengthening of local environmental management institutions to undertake improved landscape management programs
4. Develop and enforce local bylaws that influence the behavior of all land users for the common good

**Increasing Tenure Security**

Devolution of ownership of woodlands is least advanced in Africa compared to other continents. Moving forward on co-management models could enhance both productivity and sustainability of woodlands in Africa. Tenure on farms is also not well clarified or secure for farmers in the drylands. Many of those lands
have not been formally adjudicated either at the community or household levels. This not only creates uncertainty among communities and households but also creates conflicts between the state and communities. Often being seen as unutilized, some dryland areas are also prone to large-scale investments by outsiders.

More settled dryland areas normally do offer secure tenure for long-term investments, but even there, tree ownership and rights are less clear, because of the predominance of natural regeneration, the shifting of fields in and out of fallow, and the fact that some trees have been present for more than 100 years and thus have entrenched use rights to them. On top of this, forest departments in most countries protect many indigenous species which means that they cannot be pruned, felled or marketed without license. The protected trees are indigenous, which are the key trees that regenerate on farmers' fields. This discourages farmers from allowing the trees to grow. And where feasible, farmers will choose not to plant such trees but rather opt for exotic trees that are exempt from such regulations.

**Actions:**

1. Identify tenure insecurities and support negotiations to alleviate them
2. Support the piloting and eventual change toward smart forest policies that do not create disincentives for farmers to manage trees on their farms and also provide forest departments with new mandates and funding sources

**Strengthening Markets for Tree Products**

Many trends within and outside Africa are favorable for the commercialization of tree products: the new generation of farmers who are much better connected with urban areas and with ICT than their forefathers; urbanization that raises demand for wood, fruits, and other products; growing health concerns that increase markets for products like baobab and moringa; and more interest in sustainable sourcing of products giving more value to farm than forest harvesting of tree products.

At the same time, a number of obstacles remain in Africa for meeting such increased demand including: poor market information systems for tree products, poor rural infrastructure (and particularly in low populated areas such as drylands), growing but low level of collective action by farmers, low numbers of farmers participating in outgrower schemes, very little investment in basic tree product processing at scale (much done by individual farmers/collectors), and little final finishing of products (and continued imports of furniture and fruit juice ingredients, while raw products are available).

**Actions:**

1. Fund the inclusion of key tree products in market information systems
2. Support the development of outgrower schemes between processors/buyers and farmers
3. Provide venture capital and support services (for example, to gain information on preferences of consumers for processed products) for tree product processing industry

**Expanding Financing of Tree-Based Production Systems**

Tree planting requires some costs for the germplasm, for example, a seedling, as well as for labor and water. Farmers can meet these needs when they are incremental, say the planting of a few trees per year. But for significant investment in seedlings or other vegetative material, costs may non-negligible. There are several options for sourcing this finance. First, trees do provide environmental services which are hardly ever compensated for in the drylands. Carbon credit programs have not been attracted to the drylands due to the slow growth of carbon relative to the costs of monitoring, which are generally fixed per hectare. If that obstacle could be broken, there could be much more financing available to dryland areas which are vast in terms of land area.

Furthermore, although carbon accumulation per hectare is less than in humid areas, the per capita accumulation may be significant due to lower population densities. Hence, carbon finance could play a larger role in poverty alleviation. Second, within private markets, the lack of long-term credit for smallholder agriculture in Africa is widely known. There is no solution to this at hand because only recently has progress been made with respect to short-term credit for smallholders. However, for some tree products, it is possible to expand financing for tree investments through private sector processors, for which there are some examples in the case of timber in Southern Africa and fruit trees in Kenya.

Actions:

1. Provide public guarantees to facilitate long-term credit to smallholders to establish tree enterprises, as has recently been done for short-term credit for crop production
2. Develop and implement financing models that include the use of trees as collateral for lending to farmers to further expand the cultivation of trees
3. Develop effective mechanisms for capturing carbon benefits in the drylands, and use the funds to support increased TBS that help to prevent leakage and promote additionality

**Improving Tree Germplasm Supply**

Tree planting has germplasm requirements. This is a major issue for scaling up of planted trees. In typical dryland countries, germplasm systems are poorly organized, especially for native trees, due to dominance of regeneration. There may be some availability of seeds for varieties such as eucalyptus, teak, neem and mango, but little else. There is great potential for boosting collections of native trees, but some level of information and training needs to accompany this to be
able to select material that is productive, diverse and resilient to likely future climate scenarios. Multiplication of the material to serve scaling up needs is a second step in the process. Lastly, it reaches the retail stage with, for example, nursery operators.

In addition, there have been advances in vegetative propagation of some dryland species, for example, through cuttings, grafts, and marcots and these have distinct advantages in reducing the time to maturity of the tree. All of these can be done through the private sector, but the sector will need assistance from the public sector or NGOs to ensure good quality of material and may need financial support for certain fixed costs like nursery structures.

A challenge in moving forward from the public sector side is that the forestry departments normally have the mandate to support tree germplasm supply but it is the agricultural departments that better understand how trees can be best integrated with crops and livestock. Clarifying the roles of each in promoting tree germplasm for farmers is an important action to accomplish in many countries. From the private sector side, retailing or wholesaling tree germplasm is not as lucrative as other agricultural crops since annual demand by a household for any one species can be quite low, especially for fruits. These pose considerable challenges to private sector models that often thrive on economies of scale and consistent sale opportunities.

Actions:

1. Develop clear roles for forestry and agriculture in the area of assessing demand for tree germplasm and facilitating the development of a sustainable supply sector
2. Support the public sector to provide needed quality controls and training for the private sector to develop tree germplasm supply
3. Invest in the collection and multiplication of key tree species that can provide starter germplasm for the private sector
4. Support the development of private sector tree seed businesses in the dryland countries to expand the availability of tree seed for farmers

These seven policy recommendations are the most commonly needed in dryland areas. However, they are not equally important in all drylands and thus context will determine which of these deserve priority attention. For example, forest regulations restricting farmer management of trees on farms is not a critical issue in Kenya, while it is in the West African Sahelian countries. Furthermore, priorities may vary across different geographical locations within a country as market connectivity and local institutions vary. What this means in terms of a policy response or investment program is that there will be need for diagnostic work to identify the most appropriate actions to take. There is no blueprint for promoting TBS that applies in all dryland areas.
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Tree-based production systems have enormous potential to reduce vulnerability and increase the resilience of households living in dryland regions of Sub-Saharan Africa. Trees are key providers of biomass, which is critical for many livelihood needs. Wood from trees is the leading source of energy in many dryland countries and is an important construction material. Foliage and pods from trees and shrubs are the most important source of feed for camels and goats, which are the dominant livestock species in the more arid parts of the drylands. Trees and shrubs offer enhanced sources of the organic matter needed to improve the structure and raise the fertility of soils used for agriculture. Many parts of trees provide different medicinal products for people. And fruits and vegetable foliage harvested from trees are important seasonal food sources for people living in drylands, and for sale.

The benefits from trees take on added value when one considers that they are relatively impervious to many of the shocks that affect other production systems, especially livestock keeping and agriculture. Trees, with their deep rooting systems, maintain their standing value and offer some production even in drought years. They are therefore a good buffer against climatic risk and are a critical element in a diversification strategy designed to maintain levels of consumption and income in good times and bad. In addition, their value can be tapped when it is most needed: wood from trees can be harvested throughout the year, and many annual tree products are harvested at times different from the times when annual crops are harvested.

Tree-Based Production Systems for Africa’s Drylands identifies some of the most promising investment opportunities at the level of tree-based systems, species (products), and well-defined management practices for accelerating rural economic growth in the drylands.