PERFORMANCE OF INDIGENOUS TREE SPECIES IN THE SAHEL

Regreening Africa

Funded by the European Union

CIFOR

World Agroforestry

Promoting indigenous tree species in the Sahel – information on growth and management of priority species in the Sahel

Antoine Kalinganire[1,2]

Contributed to the report:
Bokary Allaye Kelly
Abasse Tougiani
Amadou Male Kouyate

1. Centre for International Forestry Research (CIFOR) – World Agroforestry (ICRAF), CIFOR- ICRAF Mali Office, Bamako, Mali
2. Commonwealth Scientific and Industrial Research Organization (CSIRO), Black Mountain, Australia
3. Institut d'Economie Rurale (IER), Bamako, Mali
4. Institut National de la Recherche Agronomique du Niger (INRAN), Niamey, Niger

A report prepared for the Regreening Africa Programme CIFOR-ICRAF, Nairobi, Kenya

November, 2022

CONTENTS

ABBREVIATIONS

AFR100	African Forest landscape Restoration (AFR100)
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIFOR	Center for International Forestry Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FAO	Food and Agriculture Organization of the United Nations
FMNR	Farmer-Managed Natural Regeneration
IER	Institut d'Economie Rurale
INRAN	Institut National de Recherches Agronomiques du Niger
ICRAF	World Agroforestry
IITA	International Institute of Tropical Agriculture
NARS	National Agronomic Research Systems
SSA	Sub-Saharan Africa
UNDP	United Nations Development Programme
UNFCC	United Nations Framework Convention on Climate Change

ACKNOWLEDGMENT

This report was prepared as a review for the Regreening Africa Program. The support and encouragement of Mrs. Mieke Bourne, Coordinator of Regreening Africa are acknowledged.

Several of the reported results have not previously been published and are based on different studies conducted by World Agroforestry (ICRAF) and its partners, the NARS in the Sahel etc. The author thanks the ICRAF and NARS scientists and the many collaborators who have contributed to the generation of those results. I am particularly grateful to those who shared substantial grey literature/documents and information on the native tree species: Dr Joseph Marie Dakouo IER Niono, Dr Bokary A. Kelly, Director of IER Regional Research Station, Sikasso, Dr Amadou M. Kouyate, Deputy Director-General IER, Dr Abasse Tougiani, INRAN Niger.

I am especially grateful to the reviewers of the draft manuscript: Dr Sammy Carsan and Dr Adja Diallo. They frequently provided additional information and ensured the text was accurate. The following provided photographs of the native species in plantations: Dr Amadou M Kouyaté IER Mali, Mr O. Samake, CIFOR-ICRAF Mali Office, Dr Adja Diallo, CIFOR-ICRAF Mali Office, Mr Adama Tounkara CIFOR-ICRAF Mali Office, Mr Pierre Dembele, Sahel Eco, Mali.

The author especially appreciates Dr Sammy Carsan and Dr Adja Diallo of CIFOR-ICRAF who provided helpful comments on an early draft of the report.

1. EXECUTIVE SUMMARY

Investments for landscape restoration in Sub-Saharan Africa (SSA) should be broadened to include sustainably managed plantations, woodlots and on-farms tree plantings or tree fruit orchards. Smallholder farmers contribute to the restoration of degraded lands and to the production of wood and non-wood products in the rural and urban areas. Trees and shrubs provide many functions and products for millions of rural households and help them out of poverty. In the Sahel, trees also play a crucial role in tempering the effects of climate, while also providing shade to facilitate the growth of crops on-farms.

To restore the degraded lands in the region, farmer managed natural regeneration (FMNR) has been used as a low-cost efficient option. However, the major challenge of the approach is a lack of species diversity, at times meaning a lack of diverse functions for farmers and growers. Therefore, to fill the diversity gap, tree planting using seeds and seedlings is suggested. However, the success of numerous projects involving tree planting in the Sahel has been limited with a very low survival of planted trees following browsing, droughts and wildfires. Moreover, the adapted species are wrongly accused as slow-growing, mainly due to slow domestication process and poor management techniques for the native tree species.

Indeed, tree planting initiatives should consider growing/cultivating trees as crops for maximum productivity. Most tree planting initiatives focus more on fast-growing exotics such as acacias, casuarinas, eucalypts, neem, senna, and white teak (gmelina) which are known to yield quick economic returns to farmers/growers from the sale of wood (timber, firewood and construction poles). Therefore, it is timely to promote the use of local tree species in plantations for wood production, increasing indigenous biodiversity, and environmental services.

The report is a review of best management techniques, including the land preparation, agronomic/silvicultural techniques for the optimum production of target wood and non-wood products and environmental services. It also highlights food and nutritional and socio-economic potential and functions provided by various species and their silvicultural attributes and growth. The importance of indigenous trees, including fruit trees, in providing economic benefits to smallholders and growers of trees are documented. For a better attention to enhanced planting of indigenous trees, key native species are presented- *Acacia senegal, Adansonia digitata, Anongeissus leiocarpum, Balanites aegptiaca, Detarium macrocarpum, Khaya senegalensis, Parkia biglobosa, Prosopis africana, Tamarindus indica, Vitellaria paradoxa, Sclerocarya birrea*, and *Ziziphus mauritiana,* showing their opportunities in terms of benefits, potential production and their possible limitations.

These are presented as they are priority tree species for domestication in most Sahelian countries, including Burkina Faso, Mali, Niger and Senegal (refer to section 4.2). It is timely to shift from the traditional tree planting of native trees mainly for improving crop and/or livestock production, human nutrition from edible fruits and nuts, but also supplying timber, construction materials, fuelwood and environmental services, to native tree growing/cultivation as tree crops. We do hope the information provided will spark out the best ways forward to scaling-up the planting and growing of native trees in the Sahel and beyond.

2. GENERAL INTRODUCTION

Rural communities and economies in Sub-Saharan Africa (SSA) countries can benefit greatly from investments strengthening forestry and the forest products sectors. Such investments, including landscapes restoration should be broadened to include sustainably managed plantations forestry and fruit tree orchards, especially those owned by small growers in forest-rural landscapes (Nambiar 2021), and on-farms. Small-scale plantation and fruit tree orchards in the SSA can be substantially strengthened by the growing demand for wood products (poles, firewood, timber, charcoal etc.), food (fruits, nuts, leaves etc.), fodder, honey, medicinal, and for recreation space, the role of forests and land restoration in the global carbon cycle and low-emissions economy, and the urgent need to uplift rural economies and reduce poverty.

Small-scale forestry/agroforestry, including fruit tree orchards, owned and managed by small growers in rural communities, is critically important for the viability of agroforestry and wood products in the drylands. Therefore, small-scale plantation/tree fruit orchards should be encouraged and strengthened as a major source of tree based commodities. Smallholders farmers in the drylands are targeted as they are actively engaged in agroforestry and in countries, unfortunately, rural poverty remains endemic, land degradation is widespread, and demand of wood and non-wood products from trees are increasing (Chomba et al 2020, Nambiar 2021).

Farmers bring into their small piece land, limited capital, and labour. They bear all the risks, over several years, before receiving returns. Their decisions, therefore, are strongly influenced by the potential growth rates of chosen species which determines the number of years to harvest and the consequent exposure to risks, but also the opportunity for early returns. The demand for specific products in the local markets is a key factor. Smallholders in the Sahel, make investments for specific tree products, prone for higher returns than what they may get from other land uses, e.g. construction poles, fruits, leaves etc. Farmers in the Sahel value the species for wood products and other essential non-wood products and environmental services such as soil-fertility improvement and soil/water conservation in their parkland agroforests (Weber et al 2008, Faye et al 2011). Faye et al (2011) stated that the product function (e.g., food, water, medicine) were relatively more important than the environmental service fucntions (eg., soil fertility and soil/ water conservation). Despite the socio-economic importance of indigenous tree species in the Sahel, communities do not traditionally plant them on their farms (Nikiema 2001). To meet the high demand of such products and for quick returns of their investments, governments, smallholders and the private sector have been investing in plantation forestry and on-farm plantings involving mainly the 'fast growing' exotic tree species, e.g. *Anacardium occidentale, Azadirachta indica, Eucalyptus camaldulensis, Gmelina arborea, Mangifera indica* and T*ectona grandis* (Kelly et al 2021b, Etongo et al 2015, Bellefontaine et al 2012).

These plantations at small-scale have improved livelihoods and economic security of rural and pre-urban households, e.g. mostly with edible fruits, poles and firewood, in a short period. Such products are being produced on a sort rotation basis, e.g. 5-7 years for Eucalypts for poles for building construction (Joseph M Dakouo, 2022.Personal Communication). There are good reasons why most small growers prefer exotic tree species. I asked farmers in Segou why they prefer growing eucalypts on their farms over local tree species: the answer was clear, sound and loud – 'for making money for my family'.

In Burkina Faso, Etongo et al (2015) stated that the main reason for planting trees include income generation from the sale of tree products. However, in the Sahel, where indigenous tree species deliver high productivity on short rotations are grown as well, e.g. *Khaya senegalensis* for timber, *Adansonia digitata* for vegetable leaves, and *Ziziphus mauritiana* for edible fruits. Such plantations are grown mainly in monocultures, mostly benefiting landholders by target products, e.g. poles or edible fruits, but those might not be the same species that maximize biodiversity, return on investment in carbon markets (Holl and Brancalion 2022) or soil and water conservation. Allowing forests to regenerate naturally in the Sahel, without planting trees is the most cost-effective strategy for recovering biodiversity, yet this does not result in the establishment of tree species that are the most economically valuable to small-holders and/or landowners (Holl and Brancalion 2022, Chomba et al 2020).

Therefore, the growing of native tree species to improve the sustainability and productivity of the drylands Sahel must be promoted. The use of indigenous tree species needs to be more attractive to local communities than the planting of exotic trees.

This report aims at giving key steps/process (refer to Figure 3.1) for conservation, successful tree cultivation with local tree species including:

- Selection of appropriate sites/conditions for conservation and tree growing to increase wood supply and restore land and reduce poverty;
- Suggestion of appropriate management practices for successful tree planting for local tree species; and
- Proposition of a few, but successful, local (indigenous/ native) tree species for tree planting in West Africa Sahel, including limitations for expansion.

There is little information about the growth and cultivation of native tree and shrubs species in the Sahel. The findings of this report are based on few published reports and grey literature available from few national researchers (list given as contributors) who contributed to the report. Moreover, 20 years' experience by the author enriched the report.

Key beneficiaries of this report are mainly tree scientists to help understanding the 'simplicity' of growing native trees in the drylands. Farmers and growers would also benefit on the performance of indigenous trees on farms for an extensive planting of indigenous trees for important functions offered by such species.

3. THE SAHEL CONTEXT

The West African Sahel, a semi-arid landscape stretching from Niger to Senegal, is rich in cultural traditions, but has some of the least developed countries in Africa. It is a transition zone between the Sahara Desert in the north, and the Sudanian Savanna to the south (Gonzalez et al 2012, Chomba et al 2020). The region has low and highly unpredictable rainfall patterns (400- 1000 mm/year) during a 3-month period followed by a 9-month dry season, high temperatures throughout the year. Population growth rate is high, life expectancy is low and particularly risky for infants and children. Illiteracy is endemic, especially among women. Burkina Faso and Niger are the countries ranking lowest on the UNDP Human Development Index, with only Sierra Leone being less developed. Improving peoples' livelihoods is a challenge for Sahelian countries (UNDP 2003).

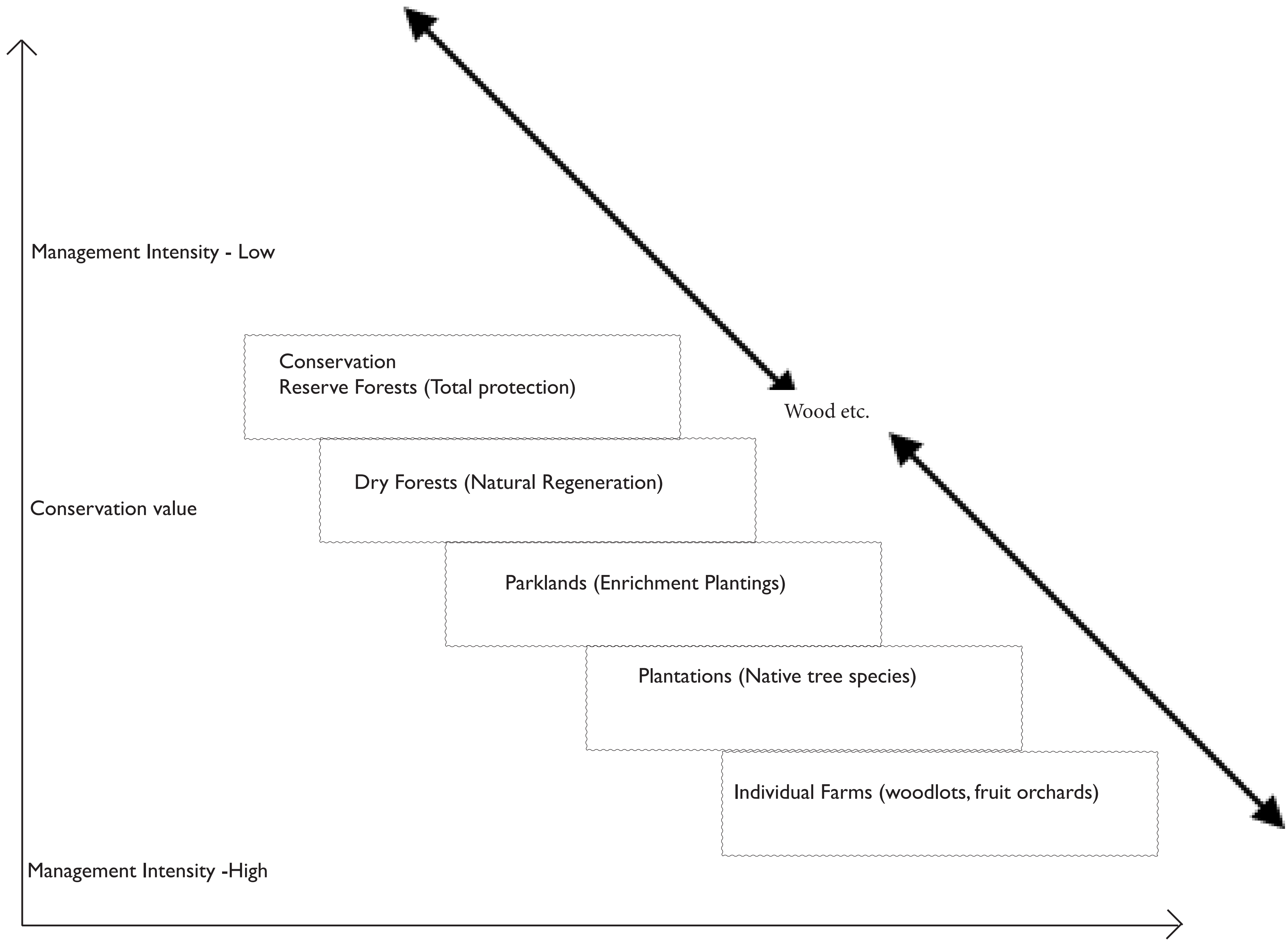
The region is characterized by a semi-arid climate, high levels of poverty, recurrent droughts, food insecurity and armed conflicts between different groups (Sinare and Gordon 2015). Few rivers and lakes provide water year around, and there are very deep-water tables in the plateaus above the rivers, and infertile soils. Moreover, there have been years of intense drought (most notably during the 1970s and 1980s), and other risks to food security due to bush fires, crop pests, parasites, etc. (Kelly et al 2021b). People in the region have evolved strategies to adapt to this harsh environment and reduce their vulnerability to risks related to climate fluctuations and extreme environmental conditions.

Nevertheless, the rate of growth in food crop production still falls short of population growth rate (approximately 2% versus 2.5% per year, respectively) (Padgham et al 2015, Kalinganire et al 2008). Currently more than 70% of the Sahelian population live in rural areas. So how do these rural people continue to survive if food crop production cannot keep pace with population growth rate? Part of the answer lies in the diversity of native trees and shrubs that people have used for generations in the parkland agroforestry system. The world's forest area is decreasing, and Africa had the highest annual net forest loss rate in 2010-2020, with 3.9 million hectares (FAO 2020). Deforestation accounts for loss of more than 60,000 hectares each year in the Sahelian countries (FAO 2006). Human activities, especially cropland expansion, overgrazing, and wood cutting have often been seen as main drivers of the change in the landscape namely changes in tree species composition and diversity, densities and their spatial distribution (Ky-Dembele et al 2019, Maisharou et al 2015).

In the Sahel, droughts and the huge pressure on land due to increased human activities have caused noticeable reduction in its vegetation cover (Zida 2020, Botoni et al 2010). There are small-scale tree planting projects by individual farmers or groups of farmers in the rural communities, rather than large-scale tree plantations initiated and supported by the national governments. In addition, some development projects funded by European governments and international donors provide technical and financial support for planting native tree species in the parkland agroforests (Ky- Dembele 2022, Weber et al 2015). However, these initiatives and strategies undertaken to reverse land degradation and desertification, have been implementing large-scale plantations of exotic plant species (Kelly et al 2021b, Chomba et al 2020), using mainly eucalypts, neem (*Azadirachta indica*) and *Gmelina arborea.* Several opportunities for reforestation in the Sahel arose with the Decade of Ecosystem Restoration.

The United Nations General Assembly declared 2021–2030 the decade of ecosystem restoration. African governments, under the AFR100 initiative, voluntarily committed to restore at least 100 million ha by 2030 as their contribution to the Bonn challenge (which targets restoration of 100 million hectares by 2020 and 350 million hectares by 2030); the 2010 Aichi Convention on Biological Diversity (which targets restoration of at least 15% of degraded ecosystems globally) and the Paris accords (CBD 2010, UNFCCC 2015). In the Sahel, we have big tree planting initiatives including: The Great Green Wall, African Forest Landscape Restoration Initiative (AFR100), etc. Unfortunately, these initiatives have not often achieved satisfactory results, particularly under extreme environmental and climatic conditions (Botoni et al 2010, Tassin et al 2009). They have at times contributed to the decline of the natural vegetation, which was cleared for the introduction of exotic tree species (Tassin et al 2009, Bellefontaine et al 2012, Soumaré et al 2017, Kelly et al 2021b). The potential of large scale tree planting to achieve restoration has been critically examined (Holl and Brancalion, 2020) and often considered costly and labor intensive, with low survival rates common where environmental constraints such as moisture and temperature are coupled with uncontrolled livestock grazing that damage young, unprotected seedlings. In the Sahel, low moisture, high temperature, prolonged dry periods, and recurrent droughts are key factors limiting tree survival with tree planting campaigns typically having survival rates of 20% or less (Rinaudo 2007, Tougiani et al 2009) especially with local tree species. The vast sums of money being spent on planting trees have the potential to transform landscapes, slow global warming (Holl and Brancalion 2020); and enhance livelihoods, food and nutrition security but will accomplish little if trees do not survive and grow. Moreover, not only environmental constraints and uncontrolled grazing are key for poor survival of planted trees in the Sahel, but also the inappropriate choice of tree species matching sites, poor tree cultivation techniques including tree nursery practices, are responsible for most plantations failures.

Figure 3.1: Process for successful tree planting in the Sahel (adapted from Nambiar 2021).



4. PREREQUISITES FOR SUCCESSFUL TREE PLANTING WITH INDIGENIOUS SPECIES

Successful tree growing with indigenous species can be met if some environmental, biological and enabling policies and markets are put in place. People plant trees for utility more than for biodiversity or carbon. Planting tree is not enough, trees need to survive and grow over years to develop a functional plantation that achieves targeted benefits by small growers especially on-farms.

In the Sahel, restoration techniques based on natural regeneration are less costly than tree planting making them a viable alternative for restoring degraded lands and for biodiversity recovery (Chomba et al 2020). However, success is likely to depend on the extent of soil degradation and the presence of forest vegetation in the vicinity (Chazdon and Guariguata 2016, Catterall 2020). Moreover, this does not result in the establishment of tree species that are the most economically valuables/needs to farmers/landowners.

This section will discuss the following key points for successful plantings as part of the objectives of this report:

- Selection of appropriate sites/conditions for tree growing to increase wood supply and restore land and reduce poverty;
- Availability of germplasm, seeds and seedlings, with appropriate genetic variability and provenance to maximize population resilience;
- Suggestion of appropriate management practices for successful tree planting for local tree species; and

4.1 APPROPRIATE SITES FOR GROWING INDIGENOUS TREE SPECIES

Careful sites selection for farmers plantings is a prerequisite for successful plantations with local tree/shrubs species. People/communities tend to wrongly allocate land for tree planting on degraded lands and good sites for agricultural crops. However, as stated by Savadogo et al (2020), sites need to be selected as per the planting objectives, e.g. timber, construction materials and firewood, erosion or windbreaks, shade etc. The choice would also consider the targeted planting locations such as line planting/fences, road planting, on-farms associated with other trees/crops or in plantations.

These are also guiding at the choice of species as discussed under section 4.2. For an appropriate selection of tree species, consider site characteristics such as steep terrain, plains, lowlands or plateaus, hill slopes, ridges, river courses, frequent flood, rocky and sandy areas etc., thus adapted species need to be selected and appropriate site management (details in section 4.3). For example, a species mixture plantings and/or enrichment planting is recommended for tolerant to pests/diseases, environmental services, ecological equilibrium and for products diversification.

4.2 SUITABLE GERMPLASM AT THE RIGHT SITE

Indigenous tree species are more adapted to the planting sites/environment in the Sahel and this would reduce the introduction of weeds or invasive species from exotic plant materials. Local availability is however not always an indicator that a species will not become invasive. Changing the management of a species (e.g. bringing it from the wild into cultivation) can cause it to become a weed (Mwaura and Dawson 2012). As earlier discussed, the indigenous species trees and shrubs have many functions for the rural communities (Kalinganire et al 2008), as sources of foods, timber and firewood, numerous traditional medicines that are essential for rural health care, and fodder and medicines for livestock.

Moreover, many of the products from the trees and shrubs are sources of additional income for the rural poor. In addition to providing products, parkland trees and shrubs provide services such as moderating temperatures, reducing soil erosion, and improving soil fertility through nitrogen fixation and nutrient cycling of their leaf biomass. Such multi-functionality of indigenous species and more adapted to the environment, are seldom provided by exotic tree species. As there is a very large number of indigenous tree species available for planting in the Sahel, to enhance tree growing using such species, it is crucial to provide to communities the appropriate species to the right sites/environment. Such species need to respond to the planting objectives (see section 3.1) and to capture the needs of communities and markets.

Priority trees and shrubs preferred by rural communities in the Sahel has been provided by Kalinganire et al (2008) and Faye et al (2011). A priority setting exercise undertaken by ICRAF Sahel in 1995 has identified the following indigenous tree species as their most preferred fruit trees to be included in the domestication programme. These include baobab (*Adansonia digitata*), ber/jujube (*Ziziphus mauritiana*), detar *Detarium microcarpum*, néré (*Parkia biglobosa*), shea tree or karité (*Vitellaria paradoxa*) and tamarind (*Tamarindus indica*). Faye et al (2011) provided the following tree/shrubs set by the Sahelian communities: *Acacia nilotica, Acacia senegal, Adansonia digitata, Balanites aegyptiaca, Cassia sieberiana, Combretum micranthum, Detarium microcarpum, Diospyros mespiliformis, Faidherbia albida, Khaya senegalensis, Parkia biglobosa, Prosopis africana, Tamarindus indica, Sclerocarya birrea, Ziziphus mauritiana* and *Vitex doniana*. Section 4 of this report gives some information on the cultivation of part of the above tree species to help for growing them in plantations and on-farms by communities.

The current understanding of population-level environmental responses in indigenous tree species planted by small-scale farmers and other growers in the Sahel is limited. However, the existing information (e.g. Muchugi et al 2021, Nyoka et al 2015, Tchoundjeu et al 2012, Weber et al 2008, Kalinganire et al 2008), show that communities need to have access to high quality planting materials (seed, seedlings, clones), an improved germplasm, for an enhanced adoption and cultivation of indigenous species. Such germplasm is either collected from natural seed stands/trees or farmland, seed production stands/orchards, and /or from selected mother trees for scions or stem/root cuttings. Their provision to rural farmers through good nursery management practices and networks (Muchugi et al 2021, Nyoka et al 2015) would avoid the use of suboptimal planting materials. As stated by Lillesø and Graudal (2012), Muchugi et al (2021), lack of access to high quality planting material and cultivation techniques of a wide-range of tree species is a frequent refrain of small-scale farmers growing trees (e.g. indigenous species) on-farms.

4.3 APPROPRIATE MANAGEMENT PRACTICES

Sahelian communities are increasingly moving towards the adoption and appropriation of techniques for planting tree species and enriching degraded forests with new species. The implementation and maintenance of different technologies varies from one type of plantation to another as earlier discussed (section 3.1).

Local tree species are considered to grow more slowly compared to some exotic species like eucalypts. However, indigenous trees have the same potential as the exotics if appropriate site conditions and management practices are provided. Indigenous species planting need to have and use improved germplasm and good site management, as good as the agricultural crops e.g., irrigation, regular weed control, use of fertilizers on degraded sites, etc. Good/sustainable site management is essential to protect site resources of soil, nutrients and water for optimum growth of the local tree species. Appropriate tree plantation management have been discussed by Savadogo et al (2020) and Kalinganire et al (2020a). For the indigenous species, important management techniques for success are herewith discussed.

Figure 4.1: Appropriate pitting for cultivation of local tree species – example of a large hole 60x60x60cm in Mandiakuy, Mali (Source: Sahel Eco, Mali).

- Large planting hole: Soil preparation prior to tree planting aims to eliminate competing vegetation, create conditions for soil to absorb and retain rainwater for water supplies, and create conditions conducive to rooting. The size of the hole dug to establish trees is critical, especially in the arid environment where soil is compacted, and water is a limiting factor for young tree development (Ky-Dembele et al 2022). It is an operation that consists of digging large holes (see Figure 4.1) at the locations to place future trees. It is recommended to dig large holes, 60x60x60 cm, but ideal is 100x100x100 cm (Ky-Dembele et al 2022), deep for optimum root development and rainwater retention for the plant. Dig hole through the lateritic soils up to the tender soil. Maybe 1 to 5 m deep – once the tender soils at 1m deep, please leave digging. A hole that is too small would suffocate the roots, results in insufficient water and nutrient availability/uptake, reduce survival rates and hinder plant growth (Oliet et al 2012, Ky-Dembele et al 2022).

Figure 4.2: Earth-bunds technique for water collection around trees and for the rehabilitation of degraded lands in Koe-Doe Mopti, Mali (Source: Ouodiouma Samake, World Agroforestry).

- Planting period: To get the most rainfall benefiting the planted tree for survival, it is necessary to plant the local trees at the start of the rainy season. Most people tend to plant their trees in August at the end of the season. For a maximum soil humidity, we recommend planting soon after the first established rains to maximize the rainy season – best after 15 May depending on countries in the Sahel – but not later than 15 June. Tree planting at the early stages of the rainy season – and/or direct sowing (Ky-Dembele et al 2022), helps to collect water reserves in the planting hole for maximum survival and growth of the plant. Apart from a deep planting hole, other appropriate and recommended techniques allowing a maximum water reservoir around the planting include mulching, zai, half-moon, soil/earth bunds (refer to Figure 4.2) with grassy strips and stones barriers to control water run-off.

- Size of the plant: Seedlings including grafted fruit trees should have reached a reasonable size prior to planting. It is recommended to have a minimum of 60 cm above root collar to avoid high weed competition. Rooted stumps are recommended for some indigenous species such as baobab (e.g. Kelly et al 2021b).

- Combatting competition and tree protection against, fire and livestock: Young trees in plantations are subject to weed competition, fire and animal damage. The competition for water between trees and herbaceous plants may be very strong. For this reason, it is recommended to weed in patches around the young seedlings every year, until the canopy closes, preventing herbaceous vegetation from developing and thus reducing water competition. The operation is carried out during the full development of the plants and continues for 2 to 3 years. Unless the area is densely covered in grass, it is not necessary to weed the whole plantation. For a maximum survival, more than 90%, it is highly recommended to protect the plantations against fire and domestic animals. For bush fires, it is advisable to weed the plantation and to mow the grass at the end of the rainy season when it begins to dry. Individual tree protection with devices (refer to Figure 4.3) against livestock is recommended at least two to three years after planting. For a plantation or fruit orchard, installation of live fences or barbed wire around the plantation is recommended.

- Vegetative propagation: The principal reason for using vegetative propagation is to capture and fix desirable traits, or combinations of traits, of individual trees (Leakey and Newton 1994, Kalinganire et al 2008). Higher yields and better products, especially for indigenous fruit trees, are desired. The adapted accessions are propagated vegetatively to maintain their desired characteristics, which would, if sexually propagated, be diluted over time. Moreover, grafting, for example, accelerates fruit precocity, thus shortening the period of first fruiting. Grafting reduces the fruiting periods, compared to trees grown from seed. The fruiting period is reduced from 20 to 3 years for *Vitellaria paradoxa* (refer to Figure 5.12), from 6 to 3 years for *Parkia biglobosa*, from more than 10 years to 3 years for *Adansonia digitata* (refer to Figure 5.3), and from 2 years to 6 months for *Ziziphus mauritiana* (Kalinganire et al 2008). Such practices lead to high yields and massive planting of native fruit trees by rural farmers. In the drylands, vegetative propagation of fruit trees is mostly done by grafting or budding or using stem cuttings.

Figure 4.3: Individual tree protection against damage by livestock in the Sahel – a 2-year old Parkia biglobosa (néré) in Mali (Source: Sahel Eco, Mali)

- Irrigation of young trees: irrigation and/or watering young seedlings in the field are good practices for young plantations during dry season. During the first two years after planting, watering ten liters (10L) per plant, per week for 2-3 consecutive dry seasons gives better height growth (Kouyate et al 2015, Hall et al 2002), except during rainy season. An easy and cheap way to water young trees is by drip-irrigation using a two-liters plastic bottles positioned in the soil near the seedling. Bottles are filled every 2 weeks (Hall et al 2002).

5. INDIGENOUS/LOCAL TREE SPECIES FOR THE SAHEL -INFORMATION ON THEIR CULTIVATION

5.1 GENERALITIES

Different regeneration techniques are tested on indigenous tree species to support governments' initiatives aiming to combat desertification and reverse land degradation (Kelly et al 2021b). Research activities on forest tree species were carried out by the Countries' Forest Research Programs of the National Agronomic Research Systems (NARS) and International Institutions such as ICRAF, CIFOR, IITA etc. Several simple and low-cost planting techniques were tested in research stations and farmers' fields by focusing on indigenous useful species (Cuny and Kouyaté 1998, Felber and Diallo 1991).

The selection and cultivation techniques of local tree species have been established, but more practical information is scanty. As earlier discussed, a priority tree species has been established. This section will focus on species that are preferred because of their multipurpose functions, including high food and nutritional potential, timber, firewood and/ as well as their medicinal and income generating values. The importance of these model indigenous fruit tree species is summarised. Information for the following tree species is given for an intensive growing of the indigenous tree species in the Sahel: *Acacia senegal, Adansonia digitata, Balanites aegyptiaca, Detarium microcarpum, Diospyros mespiliformis, Faidherbia albida, Khaya senegalensis, Parkia biglobosa, Sclerocarya birrea, Tamarindus indica, Ziziphus mauritiana* and *Vitellaria paradoxa.*

5.2 ACACIA SENEGAL (L.) WILLD. GUM ARABIC (ENG.), GOMMIER BLANC (FRENCH)

The species:

Acacia senegal (L.) Willd. [Synonym: Senegalia senegal (L.) Britton] includes four varieties: senegal, kerensis, rostrata, and leiorhachis (Fagg and Allison 2004, Bakhoum et al 2018). Other synonyms: *Mimosa senegal L, Acacia senegal var. platyyosprion Chiov., Acacia senegal subsp. modesta* (Wall.), *Acacia senegal subsp. senegalensis Roberty, Acacia pseudoglaucophylla* (Chiov.). *Senegalia senegal* is now the accepted name of what was formerly called *Acacia senegal* (Bakhoum et al 2018). Family: Leguminosae (Syn. Fabaceae) (Mimosoideae).

Main attributes and utilisation:

Acacia senegal is a multipurpose agroforestry tree species, producing gum arabic which is used for foods, beverages, pharmaceuticals, and cosmetics, and other applications (Fagg and Allison 2004).

Agroforestry systems based on *A. senegal* and a variety of crops produce combined yields that are larger than when the trees or agricultural crops are grown separately (Bakhoum et al 2018). The species promotes soil fertility and crop growth by correcting soil fertility loss, a nitrogen-fixing tree. The species provides fodder during dry periods, is used as fuelwood, develops nitrogen-fixing and phosphate acquiring symbioses with microbes (Raddah et al 2005, Lyam et al 2018). The species is an important source of income for rural populations that collect the gum arabic (refer to Fig. 5.1).

Silvicultural features:

Acacia senegal is a multipurpose tree species, very drought-resistant, and is widely distributed across Africa from the Sahelian belt to southern Africa (Fagg and Allison, 2004). The species was recently conferred to the new name *Senegalia senegal* (L.) Britton, but here we maintain the rule of priority and the name *A. senegal* is used in the present publication. *Acacia senegal* is well adapted to arid zones, drought tolerant, with low soil fertility and a seasonal rainfall varying between 200 and 800 mm (Diatta et al 2021, Fagg and Allison, 2004).

The species occurs in the tropical summer rainfall zone, with a single short rainy season of 3-4 months, and dry harmattan winds contributing to a long and severe dry season. Climate has a major influence on gum production, and under high rainfall such as in the highlands of east Africa, little gum appears to be produced. It is most common in areas with 300-400 mm rain per year but can growing areas with as little as 100 mm, and a dry period of 8-11 months (Joker 2018a). Altitude range 100-1700 m.

Figure 5.1: Gum arabic products collected in a progeny-trial at Dahra, Senegal (Source: Adja Diallo, CIFOR-ICRAF Mali Office).

The species is found across a wide range of soil type, from poor sandy soils to sandy clays, and lithosols over quartz, as well as in saline soils (Diallo et al 2016). It prefers well-drained sandy soils (Joker 2018a). Gum arabic is collected from the tree, and provides an important source of income for rural populations that also use the species for other products. The ability to fix nitrogen and tolerate drought impacts makes *A. senegal* an essential component of dryland agroforestry systems and the species is therefore widely recommended in most reforestation programs in the Sahel. It is also recommended for on-farms plantations.

The species is propagated either by seed or rooting for young trees (Diatta et al 2021). Seeds are soaked overnight in the hot water, with a germination rate over 80% (Doumbia Modibo, Unpublished Data). Growth rates from trees in plantations vary considerably between environments, and provenances and ploidy levels (Diatta et al 2021, Diallo et al 2016). Therefore, information about provenance as well as ploidy status must be considered while establishing new plantations. The correct provenance needs to be used in plantations. In the Sahel, the species can grow more than 1m per year (Raebild et al 2003). However, more than 2 m per year has been recorded on some sites in Niger, and in Senegal (see Figure 5.2a and b). Plantations are established from potted seedlings in large holes, minimum of 60x60x60cm. Larger holes are suitable for the establishment of plantations. Direct sowing of seeds, is a cheap method of establishing plantations in the Sahel. This technique gave more than 80% survival (Ky-Dembele et al 2022).

Diseases and pests:

Both bacteria and fungi are commonly found in the gum arabic. Moreover, we have parasites belonging to the genus Loranthus spp., tending to attack ageing trees. However fungal diseases are not a major problem. The seed is very susceptible to insect attacks.

Environments with high rainfall have low gum production. Early tapping and over- tapping are also a threat to the tree survival and gum production.

5.3 ADANSONIA DIGITATA L. AFRICAN BAOBAB (ENGLISH), BAOBAB (FRENCH)

The species:

Adansonia digitata L. (Baobab) (Synonyms: *Adansonia bahobab L., Adansonia integrifolia Raf., Adansonia sphaerocarpa A.* Chev.). Baobab and its related species belong to the family Bombacaceae and the genus Adansonia.

Main attributes and utilisation:

Baobab (*Adansonia digitata L.*) is a large, majestic multipurpose tree with medicinal and cosmetic properties, numerous food uses of various plant parts, and bark fibres that are used for a variety of applications (Gebauer et al 2011). Wild tree fruits constitute an important part of household diet and are a source of income for rural farmers, thus contributing to the eradication of extreme poverty and hunger. Baobab is one of the most widely used wild trees providing food, medicine and fodder in Africa (Assogbadjo et al 2012).

Limitations:

Figure 5.2: A 28-year old progeny trial plantation of Acacia senegal growing at Dahra, Senegal -(rainy season, (5.2b) dry season

The fruits and leaves of baobab are important sources of income in the Sahel. Leaves are used to prepare sauces and fruit pulp to make beverages. The pulp constitutes the most valuable product, it has a high content of calcium and phosphorus and high levels of vitamin C (Parkouda et al 2012, Teklehaimanot 2008, Diop et al 2005). The leaves are rich in vitamins B1, B2 and C, sugars, potassium tartrate, and calcium (Sacande et al 2018, Maranz et al 2007, Bosch et al 2004). In Mali, some ecotypes were reported to have fruits with exceptionally high vitamin content (Kalinganire et al 2008). They are cooked fresh as a vegetable or dried and crushed for later use. The root of very young trees is reputed to be edible as well as the seeds which can be roasted for use as a coffee substitute. Leaves, shoots and fruits are used as fodder. Most parts of the tree are used medicinally for a variety of illnesses (Sacande et al 2018).

Silvicultural features:

The African baobab occurs naturally in most countries south of Sahara. In the Sahel it is naturally occurring from Chad in the east to Senegal in west. As reported by Sidibé and Williams (2002), baobab is associated with the savannas, especially the drier parts of West Africa. The species is sensitive to inundations (Orwa 2009). It is usually located at low altitudes (up to 1000 m), with mean annual rainfall of 100-1000 mm (Sacande et al 2018). It occurs on well-drained soils.

The species is propagated by seed, through seedlings production in the nursery or by direct sowing in large holes. Seeds are soaked in boiling water, and left to cool overnight, and have a germination rate over 80% (Doumbia Modibo, Unpublished Data). The seeds that swell are sown, and the remaining seeds re-immersed, until they also swell (Sacande et al 2018). Survival and growth of local baobabs in the Sahel are interesting. Early growth at Samanko (Mali), trees grown from grafted seedlings were more than 3 m (Modibo Doumbia, Unpublished data) one-year after planting. Moreover, a species trial revealed better growth of *A. digitata* compared with other Adansonia species (Maranz et al 2008). Kelly et al (2021b) reported the survival and growth of *Adansonia digitata* of 15-months old tall bare-roots plants (saplings) were grown on-farms at Bankass (Mali).

The mean survival was 82% and was higher than of those planted by using container seedlings (59%). The mean annual height increments of tall bare-roots (34 cm year−1) was higher than that of container seedlings (22 cm year−1). Based on these findings, tall bare-roots of *A. digitata* could be successfully used for enrichment plantings and plantations.

More widely, tall bare-roots of *A. digitata* could be used in large scale restoration in similar contexts. In Niger, 4-year container-grown baobab seedlings, in a provenance trial, showed an annual height increment of up to 40 cm and more than 90% survival for some most provenances (Kalinganire et al 2022).

However, grafted and potted seedlings had higher growth than non-grafted plant materials. At Samanko, Mali, a 5-years old grafted baobab (refer to Figure 5.3) started fruit production at 3 years. Plantations of baobab (refer to Figure 5.4) started production at 3 years and at its optimum fruit production at 20 years. Irrigation of grafted seedlings increased significantly fruit production compared to non-irrigated trees. Thus, the use of grafted seedlings and frequent irrigation during dry season at the early planting time are more recommended for plantations and for baobab based fruit orchards.

Pests and diseases:

None recorded. Appears to be relatively resistant to termites.

Limitations:

Seedlings require protection from browsing livestock in initial stages of growth. If fruit production is the main objective, and for optimum fruit production, trees should be kept away from leaf collection. Livestock feeds on the young trees.

Figure 5.3: Early fruiting, at 2 years, of a five-year old baobab (*Adansonia digitata*) grafted tree at Samanko, Mali (Source: Antoine Kalinganire, CIFOR-ICRAF Mali Office).

Figure 5.4: A 20-year old baobab (*Adansonia digitata*) plantation at Samanko, Mali (Source: Adama Tounkara, CIFOR-ICRAF Mali Office).

5.4 ANOGEISSUS LEIOCARPUS (DC.) GUILL. ET PERR. BOULEAU D'AFRIQUE (FRENCH), AFRICAN BIRCH ENGLISH)

The species:

Anogeissus leiocarpus (DC.) Guill. et Perr. (*African birch*) (Synonym: *Conocarpus leiocarpus DC, Anogeissus schimpei Hochst. ex Hutch. et Dalz., A. leiocarpus var. schimperi* (Hochst. ex Hutch. et Dalz.) Aubrev. African birch belongs to the family Combretaceae.

Main attributes and utilisation:

The African birch has a hard and resistant wood to termites and insects' attacks, excellent wood for building constructions. It is an excellent firewood and for charcoal production. It is used in several traditional medicines to cure various diseases. Leaves are also used as cattle feed - fodder. Dye is extracted from back for traditional cotton clothes.

Silvicultural features:

Anogeissus leiocarpus, an evergreen tree can reach 30 m tall. The species occurs naturally in Senegal, Sudan and Ethiopia and extending to northern Congo (RDC) (Andary et al 2005, Arbonnier 2000, Maydell 1986). The species is found on wet soils, especially around ponds, river banks and forest galleries. It is managed through natural regeneration and by coppices after a careful and clean tree felling. Coppices need to be protected against livestock at least for 3 years. Clear cutting of a 19-year old *Anogeissus leiocarpa* plantation was found better than selective cutting regarding the percentage of stump bearing shoots (97% versus 87%) (Kelly 2011). The mean number of shoots per stump (12) was the same for the two cuttings. Coppicing artificial stand of *A. leiocrapa* is feasible and is recommended. Neither fire nor weeding did compromise the ability of sprouting and shoots growth of the species. In plantations, the species is propagated by seed. Seeds are soaked overnight in the cold water, with a germination rate over 85% (Doumbia Modibo, Unpublished Data). The mean annual height increment was more than 60 cm/year (Kelly 2011), growth of more than 1 m per year has been reported 8 years after planting (Kelly and Cuny 2000, Louppe and Ouattara 1996). Anogeissus leiocarpus is successfully grown in plantations in both Mali and Burkina Faso. Clear cutting appears to be an appropriate option for coppicing this tree species since it offered a high percentage of stumps having sprouted, a high number of shoots per stump and a good growth of shoots.

Limitations:

The species is very sensitive to fire (Dayamba et al 2008). Low germination rate of seeds following general poor seed viability limits the production of seedlings for plantations.

5.5 BALANITES AEGYPTIACA L. DEL. DATTIER DU DESERT (FRENCH), DESERT DATE (ENGLISH)

The species:

Balanites aegyptiaca L. (Del) is a wide-range species that belongs to the Balanitaceae family. Some synonyms include the following: *Agialid aegyptiaca (L.) Adanson, Agialida senegalensis van Tiegh., Agialida barteri van Tiegh, Agialida tombuctensis van Tiegh., Balanites zizyphoides Mildr. et Schlechter, Ximenia aegyptiaca (L.).*

Main attributes and utilisation:

Balanites aegyptiaca is one of multipurpose plants in the Sahel very appreciated by the populations. Most parts of *B. aegyptiaca* produce some food product (Hall and Walker 1991). The species provides many products for rural and urban communities in the West African Sahel, including food, fodder, medicines, and wood (Faye et al 2011).

The wood is hard, durable and easy to work with, but the small stem size and the tendency to flute makes sawmill processing difficult (Schmidt and Joker 2018). It is a fruit tree from the Sahelian and Sudano-Sahelian zones. It provides a source of income for communities and its various parts are used for human and animal food, handcrafts and traditional medicines. The seeds are rich in proteins and energy (Teklehaimanot 2008). Fruits are eaten raw and their almonds are transformed into oil and soap (Abdou-Habou et al 2019, Weber al 2008). Roasted kernels have good potential for commercial food production for human consumption. Pressing the kernel yields a good quality oil. After oil extraction, kernel cakes can then be used for animal (forage or processed feed).

Silvicultural features:

The species is reported as a shrub or a small tree to 10 m (rarely up to 15 m) high. The species is native to semi-arid regions in Africa from Senegal to Sudan and from Egypt to Zambia (Hall and Walker 1991, Arbonnier 2000). The core of its distribution is the Sahel. The tree is mainly propagated from fresh seed by direct seeding or seedling production in the nursery (Weber et al. 2018, Hall and Walker 1991). Fresh seeds need no pre-treatment (Schmidt and Joker 2018).

However, seeds that have been stored will normally need manual scarification. Soaking seeds in warm water for 18 - 24 hours and left to cool in the water, gives more than 90% germination (Schmidt and Joker 2018, Doumbia Modibo, Unpublished data). However, seed extracted from cores that have passed into the digestive tract of goats gave the germination rate of 76.87%) (Abdou-Habou 2019). Therefore, production of *Balanites aegyptiaca* plants in nurseries and for plantations is easy. The species has a wide ecological distribution. The species grows on a range of soil type and climate, reaches its maximum development on low-lying, level alluvial sites with deep sandy loam soil and uninterrupted access to a source of water (Schmidt and Joker 2018). The tree grows best on deep clayed or gravel soils such as on valley floors, river banks and at the foot of rocky slopes (Kouyaté et al 2015, Hall and Walker 1991). It is a lowland species growing up to 1000 m altitude in areas and a mean annual rainfall of 250-400 mm (Schmidt and Joker 2018). It is a shade-intolerant and grows above a single-stemmed or multi-stemmed shrub, produces a deep taproot, sprouts after coppicing, spreads asexually from sucker shoots, starts producing fruits after 5-7 years (Weber et al 2018). In Mali, plantations have been established with an initial survival of more than 80%. Growth is considered slow, with an initial growth of about 30cm per year (Hall and Walker 1991), but in Mali on suitable sites, a height growth of about 1.2 m per year has been attained. With good management, the species gives excellent growth in plantations and on farms. Trees are established in large holes, 60x60x60cm, (Kouyate et al 2015), but 100x100x100 cm are recommended. Frequent weeding around the plant, twice a year are recommended. Protection against browsing by domestic animals needs to be done.

Figure 5.6: A 20-year old *Balanites aegyptiaca* tree grown in a mixed plantation at Samanko, Mali (Source: Adama Tounkara, CIFOR-ICRAF Mali Office).

Pests and diseases:

Seeds are susceptible to infestation by an insect borer. Appears to be relatively resistant to termites.

Limitations:

Water is the main limiting factor to the optimum growth of *Balanites aegyptiaca* in the Sahel.

5.6 DETARIUM MICROCARPUM GUILL. ET PERR. PETIT DETAR (FRENCH), SWEET DATTOCK (ENGLISH)

The species:

Detarium microcarpum Guill. & Perr. is a deciduous tree of the family Fabaceae (Cronquist, 1988).

Main attributes and utilisation:

Detarium microcarpum is a valuable tree species for fuelwood, timber, food and medicine in sub-Saharan Africa. The fruit of *Detarium microcarpum* is consumed raw or cooked. When fruits are processed into cakes, they are sold at local and regional markets (Kouyaté 2005). Fruits are sold to the Senegalese merchants along the Mali-Senegal railway. The pulp is used for making an alcoholic drink and for the preparation of couscous. Kouyaté (2005) gives the following nutritional values of 3.2 mg of vitamin C for 100g; 4.9 g of proteins for 100 g and 64.5 g of nutritional sugar for 100g. Some people in Mali use it as sugar substitute. It contains 4.9 g of proteins for 100 g of total weight (Kouyaté 2005).

Other utilisations include traditional house construction, medicinal and cultural uses. In Burkina Faso, fruits are used in the treatment of meningitis (Bationo et al 2001). Leaves of *D. microcarpum* are used in thatching of roofs of houses. The wood of *D. microcarpum* is used as fuelwood, construction poles and tool handles (Kouyaté 2005). Seeds of *D. microcarpum* are used as scents (from dried and grounded seeds), and as necklaces from dried seeds. As reported by Kouyaté (2005) these necklaces, would have an aphrodisiac effect due to their nice smell. Roots are used as a mosquito repellent. Seed, fruit, leaves; roots and barks are all used for medicinal purposes. Leaves and roots of detar are used for treating animal diseases. Moreover, *Tapinanthus globiferus* a parasitic plant on *D. microcarpum* is used for magical ritual. The species has the potential to contribute to food security in the Sahel and for income generation to rural communities (Bernard et al 2019).

Silvicultural features (establishment, growth/yield):

Detarium microcarpum (detar) is a deciduous tree. It is found in semi-arid sub-Saharan Africa from Senegal to Cameroon, extending east to the Sudan. It has an irregular distribution, but it can be locally very common. Typically, it is found in high rainfall savanna areas, dry forests and fallow lands on sandy or iron rich hard soils as well as scattered trees on farms. It also occurs in dry savanna as a more stunted tree with smaller fruits reaching ca. 10 m high; in wet areas it can grow up to 25 m tall (Arbonnier 2000, Ky-Dembele et al 2010). The fruits that are drupe-like, circular and disc shaped, containing fibers are edible and rich in vitamin C, potassium and calcium.

The species thrives in a variety of soils including degraded and rocky areas with an annual rainfall of about 600-1000mm (Bernard et al 2019). It is retained on-farms for soil improvement through nitrogen-fixation and leaf litter decomposition, fuelwood, food and medicinal purposes.

The species is mainly managed in natural forests, but can grow in plantations for its multiple benefits to communities. Information on its establishment in plantations is very scanty. Seedlings are grown in the nursery after seed is immersed in cold water for 48h (Bernard et al 2019). This is the most efficient pre-treatment for the species with up to 98% germination rate. However, the use of clonal propagules will ensure successful plantation for the species (Ky-Dembele et al 2008 and 2010); e.g. propagules from root cuttings (Thibaut 2008). Direct sowing on-farms and in plantations on large planting holes is recommended.

Figure 5.7: A 3.5-year *Detarium microcarpum* plantation irrigated for 2 consecutive dry seasons at Farako Research Station, Mali (Source: Amadou M Kouyaté, IER Bamako, Mali)

Pests and diseases:
None recorded. Appears to be relatively resistant to termites.

Limitations:
Water stress is a major limiting factor for an optimum plant growth and biomass production. But, a technology has been developed in IER Mali to irrigate with 20 liters of water per plant, per week during 2 consecutive dry seasons (refer to Figure 5.7). Today, this plantation is unique in the distribution area of *Detarium microcarpum* (Kouyaté 2012).

5.7 KHAYA SENEGALENSIS (DESR.) A. JUSS – AFRICAN MAHOGANY (ENGLISH), CAILCEDRAT (FRENCH).

The species:
Khaya senegalensis (Desr.) A. Juss (African mahogany or Cailcedrat) is a member of the *Meliaceae* family, in the subfamily *Cedreloideae*; synonym: *Swietenia senegalensis Desr.*

Main attributes and utilisation:
Khaya senegalensis is a majestic tree species and an integral part of tropical Africa's northern savannah landscape (Opuni-Frimpong et al 2016, Gauove and Ticktin 2008, Aubréville 1950). It produces one of the world's finest cabinet timbers (*African mahogany*) and contributes greatly to the welfare of millions of people across this region (Joker and Gamene 2018, Sexton 2013, Orwa et al 2009). Apart from timber, Sahelian communities use the species for fuelwood, medicine (especially the bark), building materials, shade tree and fodder (leaves) for their livestock.

Because of its value as a timber species and the pressures of a growing population dependent on natural resources, this species is rapidly being removed from the landscape. In West Africa the seed oil, rich in oleic acid, is used for cooking. The wood ashes are used for storing millet seed.

Silvicultural features:
Khaya senegalensis is a medium sized tree reaching heights of between 25-35m, with a trunk diameter of up to 1.5 m (Arbonnier 2000). However, on deep alluvial soils where soil moisture is maintained, this species can reach heights of between 40-55 m, with a trunk diameter of exceeding 2.0 m (Sexton 2013). The height and form of this species is often curtailed by low rainfall and impoverished shallow soils. The natural habitat of this species covers a broad range of environmental, climatic and edaphic conditions that stretches between the coastal plains of Senegal to the White Nile valley in South Sudan and Uganda. To the north of its range, *Khaya senegalensis* occurs along the steppes of the Sahara and as far south as the fringes of the equatorial rainforests. This environment covers a multitude of soil and vegetation (with grass) types. The species grows at 0-800 m altitude in areas with a climatic gradient stretching from 400-1,500 (1,750) mm rainfall per year and a dry season of 4-7 months (Joker and Gamene 2018).

The species is light-demanding, establishes well on a wide range of soils from well-drained and fertile soils including clay-loam, to sandy. The species can be planted as a single species in plantations, mixed species and on-farms in agroforestry. Mixed species or agroforestry will increase product diversity and help plants to be resistant to the shoot-borer (*Hypsipyla robusta*) (Opuni-Frimpong et al 2016, Sokpon and Ouinsavi 2004). Mature trees of *K. senegalensis* are tolerant of drought, fire and seasonal inundation (Orwa et al 2009). Propagation is seed in sown in the nursery, seeds soaked overnight in the cold water, or through direct sowing. However, Joker and Gamene (2018) reported the seeds are not dormant and pre-treatment is not necessary.

Figure 5.8: A 20-year old *Khaya senegalensis* tree road plantation at Samanko, Mali (Source: Antoine Kalinganire, CIFOR-ICRAF Mali Office).

Under optimal conditions, trees can reach heights of over 50 m but generally grow to a height of between 20 and 30 m (Sexton 2013). In plantations, Louppe and Ouattara (1996) reported an annual height increment of more than 0.7m. The species attains an initial growth of about 1.0 m a year, but on suitable sites on-farms with large holes, a height growth of more than 1.5 m per year has been obtained (Antoine Kalinganire, Personal observations) at the first 3 years of growth (refer to Figure 5.8). With good management, the species gives excellent growth in plantations and on farms.

Pests and diseases:

The species in plantations is attacked by a shoot-borer *Hypsipyla robusta*. The seeds in storage are sometimes heavily attacked by larvae.

Limitations:

The decapitation of *K. senegalensis* trees for fodder is prevalent during the dry season across the northern savannah belt. Trees are stripped bare of their foliage to provide fodder for livestock, removing any possibility of pollen or seed dispersal.

5.8 PARKIA BIGLOBOSA (JACQ.) R.BR. EX G.DON. NÉRÉ (AFRICAN LOCUST BEAN)

The species:

Parkia biglobosa (Jacq.) R.Br. ex G.Don, the *Mimosaceae* family. Synonyms: *Mimosa biglobosa Jacq., Parkia africana R.Br.*

Main attributes and utilisation:

Néré is an important multipurpose tree species, and one of the most common traditional parklands species which provides vital non-timber forest products. Such products and its economic values have been discussed (e.g. Kalinganire et al 2008, Teklehaimanot 2008, Hall et al. 1977).

Farmers keep *Parkia biglobosa* trees on their farms due to its valuable non-wood products and its capacity to improve soil. In the parklands, néré is associated with a range of crops, but mainly with large leafy vegetables and less with groundnuts and cereals such as maize and millet. Néré is valued for the seeds that are ground into a nutritious spice or condiment, soumbala, which is added to soups and stews throughout the Sahel.

The seeds provide an important source of proteins. The seeds may be sold for commercial processing and sold as fresh soumbala on local markets. As stated by Teklehaimanot (2008), the value of the seeds increases significantly once processed. The fresh fruit pulp contains a high percentage of sugar and can be fermented into a drink. Ouedraogo (1995) and Teklehaimanot (2008), reported the nutritional values of seeds and fruit pulp of néré. Seeds are rich in proteins, lipids, carbohydrates and phosphorous while the fruit pulp is high in carbohydrates, vitamins C and B2 (Lamien et al 2011), and mineral compounds.

The flowers are also consumed. Néré, the tree legume is also a source of fodder. Parkia branches are usually lopped by the farmers and fed to livestock, especially in the dry season when good quality feed is scarce. Human medicine is one of the principal uses of néré in West African Sahel; and is also used in traditional ceremonies (Teklehaimanot 2008, Lamien et al 2011).

All parts of the plant are used to cure many human diseases including malaria and stomach disorders. Moreover, different parts are used for treating human and animal diseases, and the seed coats all used as a fertiliser. The wood is suitable for kitchen implements, carving, firewood, house and musical items from pods fibers and roots.

Silvicultural features:

Parkia biglobosa (néré) is a deciduous savanna tree attaining up to 20m high, a component of anthropic landscapes than of the natural landscapes and is particularly characteristic of agroforestry parklands (Teklehaimanot 2004). The natural range of African locust bean covers a broad area extending from Senegal in the west to Uganda in the east and includes Sudanian as well as Guineo–Congolese zones (Lamien et al 2011, Hall et al 1997). The species grows under a wide range of conditions, where annual rainfall ranges from 600 to 1500 mm and the dry season lasts 5–7 months. It occurs in natural and semi-natural habitats such as savannahs and woodlands, sometimes on rocky slopes, stony ridges and sandstone hills (Lamien et al 2011).

Farmers manage néré in the parkland because of its valuable non-wood products and its capacity to improve soil fertility. In the parklands, néré is associated with a range of crops, especially large leafy vegetables, but also with groundnuts and cereals such as maize and millet. The species is mainly propagated by seed. Direct sowing has been regarded as more convenient for a rapid propagation of the species (see Figure 5.9).

Mechanical scarification of the seed is very effective for breaking dormancy and improving the seedlings vigour (Okunlola et al 2011). The immersion of seed in hot water overnight before sowing (Lamien et al 2011) in the recommended pre-treatment. Grafted néré, as another propagation method, reduced the period to the first fruiting from 20 years to 6 years (Kalinganire et al 2008). The species thrives on deep alluvial soils, may reach more than one metre of height per year in plantations from seedlings (Sina 2006, Houndonougbo et al 2020), but with better results with grafted plant materials (Antoine Kalinganire, Personal Observations). It should be emphasized that management practices (size of the hole, weeding, fertilizers application, irrigation etc) play an important role in the growth of the species (Kelly et al 2021a). For better results in the cultivation of *P. biglobosa*, it is recommended to apply the best/optimum management practices, including protection of the planted trees, as discussed under section 4.3 of this report.

Figure 5.9: A one and half (1.5) - years néré tree grown by direct sowing on-farm at Mandiakuy, Mali (Source: Sahel Eco, Bamako, Mali).

Institutional arrangements in the village disfavour regeneration of *P. biglobosa* as the trees belong to land chiefs. For *P. biglobosa* to regenerate it will be necessary to introduce direct sowing and/or plantations of the species, as well as to find a solution to the conflicting interests (Raebild et al 2012).

Pests and diseases:

The species is reported to be attacked by termites (Kelly and Cuny 2000).

Limitations:

Lack of regeneration of *P. biglobosa* seems to be due to intensive seed harvest for food processing, leaving few seeds to germinate, and browsing animals destroying individuals that germinate.

5.9 PROSOPIS AFRICANA (GULL. ET PERR.) TAUB. (IRON TREE, AFRICAN MESQUITE) (ENGLISH).

The species:

Prosopis africana (Gull. et Perr.) Taub., the *Mimosaceae* family. Synonyms: *Coulteria africana Guill. et Perr, Prosopis oblonga Benth.*

Main attributes and utilisation:

Rural communities in West Africa value the species for wood products, fuel, medicines, food, fodder, and environmental services such as soil-fertility improvement and soil/water conservation in their parkland agroforests (Weber et al 2008, Faye et al 2011). Because *P. africana* provides several essential products and environmental services to rural communities, farmers in some rural communities (particularly in Niger) plant seedlings and manage natural regeneration of *P. africana* in their parkland agroforests. Leaves and pods are used by farmers for animal food, and the bark and roots are used to treat diseases. Its wood is resistant to decay and is used to make households tools, charcoal and poles for construction (Laouali et al 2015a).

Silvicultural features (establishment, growth/yield):

Prosopis africana attains up to 20 m high; and grows preferably on deep alluvial and/or sandy clay soils (Arbonnier 2000, Kelly and Cuny 2000). It has a natural distribution from Senegal to Ethiopia in the north, from Guinea to Cameroon in the south, and from Uganda to Egypt in the east; but it has disappeared from extensive parts of its range due to over-exploitation, such as excessive cutting of stems and branches resulting in limited natural regeneration (Laouali et al 2015a, Pasiecznik et al 2004).

In West Africa, it extends throughout the Sudanian and Guinean ecozones in the southern part of its range and into the Sahelian ecozone in the northern part of its range. It does not tolerate habitually dry sites, preferring 600–1500 mm annual rainfall. *Prosopis africana* trees produce deep taproots, grow slowly above ground, and can be coppiced for successive harvests (Pasiecznik et al 2004).

Prosopis africana is better propagated by seedlings and mechanical scarification is quite a suitable approach to break seed dormancy, with a germination rate of 85% (Laouali et al 2015b, Ahoton et al 2009), but seed soaked in hot water and cooled down for 48 hours gives the same results (Modibo Doumbia, Unpublished data), and is the best pre-treatment.
The initial tree growth of the species is relatively fast, more than 0.8m height growth per height (Laouali et al 2015b, Louppe and Ouattara 1996); but up to one meter height growth on deep alluvial soils in Niger (Antoine Kalinganire, Personal Observations). However, Weber et al (2015) reported a total height growth of 4.2 m 13 years after planting (refer to Figure 5.10).

Limitations:

Extremely low fruit production is limiting its propagation from seeds. Therefore, its propagation by air layering is possible, although with a low success rate (Laouali et al 2015a).

Figure 5.10: A 25-year *Prosopis africana* tree cultivated at Samanko, Bamako, Mali (Source: Antoine Kalinganire, CIFOR-ICRAF Mali Office).

5.10 TAMARINDUS INDICA L. TAMARIND (ENG.), TAMARINIER (FRENCH)

The species:

Tamarindus indica L., belongs to the Leguminosae: *Caesalpinioideae* Family. Synonyms: *Tamarindus occidentalis* (Gaertn); T*amarindus officinalis* (Hook) and *Tamarindus unbrosa* (Salisb)

Main attributes and utilisation:

Tamarindus indica (Tamarind) is a multipurpose tropical fruit tree used primarily for its fruits, which are eaten fresh or processed, used as a seasoning or spice, and seeds are processed for non-food uses. In the Sahel, the fruit pulp is also used primarily for sauces, porridge and juice.

Tamarind can be used as a snack, in sauces, confectionery, drinks, jam, ice cream, wine, and as a coffee substitute, food stabilizer, animal fodder, edible oil and medicine (Kalinganire et al 2008, Maundu et al 1999). It is also a valuable timber species (Joker 2018b).

The pulp fruit has low water content and high levels of proteins, carbohydrates and minerals (potassium, phosphorus, calcium and iron); but is very poor vitamins A and C (El-Siddig et al 2006). Tamarind fruit pulp is nutritious and is rich in tartaric and ascorbic acids and is used as an important natural preservative in pickle industry (Nagarajan et al 1998). The pulp fruit has low water content and high levels of proteins, carbohydrates and minerals (potassium, phosphorus, calcium and iron); but is very poor vitamins A and C (El-Siddig et al 2006). In the Sahel, the fruit pulp is eaten raw, but local varieties have a strong acidic taste compared with sweet-tasting cultivars introduced from China and Thailand (Samake et al 2014).

Tamarind wood has many uses including making furniture, mortars, pestles, canoes and tool handles. Tamarind heartwood is a very durable timber and is used in furniture making as it takes on a good polish (El-Siddig et al 2006). The wood is also good for firewood and for charcoal making. Tamarind products, leaves, fruits and seeds have been extensively used as herbal medicines. Several medicinal properties are claimed for preparations containing tamarind pulp, leaves, flowers, bark and roots. The seed is also a good source of protein and oil (Teklehaimanot 2008).

Silvicultural features:

The species has a wide geographical distribution in the sub-tropics and semi-arid tropics and is cultivated in many regions. It is a long-lived, large evergreen or semi-evergreen tree, 20-30m tall (El-Siddig et al 2006). As per Arbonnier (2000), it is native in Burkina Faso, Cameroon, Central Africa Republic, Chad, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali, Niger, Nigeria, Senegal, Sudan, Tanzania and Uganda. Tamarind is adapted to a wide range of ecological conditions, reflecting its wide geographical distribution in the sub and semi-arid tropics. Mean annual rainfall of 400 to 1500 mm per year, but tolerates down to 350 mm if irrigated at the time of establishment (Joker 2018b). Regardless of total annual rainfall, it produces more fruit when subjected to a long dry period (Joker 2018b).

Figure 5.11: A 16-year old tamarind tree in Samanko, Mali (Source: Adama Tounkara, CIFOR- ICRAF, Mali Office).

The tamarind tree grows in a wide range of soils, but thrives best in loamy, deep and well drained alluvial soils. Silt-clay and clay soils are not appropriate for tamarind plantations (Kelly and Cuny 2000). Deep and well drained soils. Tamarind is traditionally grown from seed, but vegetative propagation through cleft-grafting and grafting per approach methods is also used (Samake et al 2014). Germination of tamarind can be accelerated by mechanical scarification; soaking seed in hot water and left cooling down overnight gives more than 90% germination rate (Modibo Doumbia, Unpublished data), and is recommended. Annual height increments of 0.6 m (Kelly and Cuny 2000) has been reported, but also 1.5 m initial growth on good soils (Snauwaet 2009).

Pests and diseases:

Tree-rots and bacterial leaf spots are reported. Leaf spots are very common in the Sahel. Mildew is a common occurrence in tamarind nursery seedlings. Seed borers attack pods on the tree. Insect attack during storage can be a major problem (Joker 2018b)

Limitations:

The tree does not tolerate water-logging.

5.11 VITELLARIA PARADOXA C.F. GAERTN. SHEA (ENGLISH), KARITÉ (FRENCH).

The species:

Vitellaria paradoxa (Gaertn C. F.) (Family: Sapotaceae), commonly known as Karité (French), Shea (English).

Main attributes and utilisation:

Vitellaria paradoxa (Gaertn C. F.) (Sapotaceae), commonly known as Karité (French) or Shea (English), is a multipurpose tree, producing an edible fruit that is the source of one of Africa's oldest food oils (Muchugi et al 2021, Kalinganire et al 2020b, Hall et al 1996).

The importance of the species has been extensively discussed by Hall et al (1996) and Teklehaimanot (2008), and its nutritional values by Maranz et al (2004). Shea butter, extracted by processing nuts of ripe fruits through roasting, crushing and boiling of the butter paste which is rinsed multiple times, is the main product of the shea tree (Joker 2018c, Boffa 2015), and is sold in both local and international markets, while the fruit pulp is eaten fresh. Shea butter has become a dynamic industry because of its importance as raw material for chocolate, cosmetic and pharmaceutical products (Ky-Dembele et al 2021, Sanou and Lamien 2011).

The butter is used in chocolate, confectionery and personal care industries as a substitute for cocoa butter. Its oil fraction is used in margarines and for baking in place of olive oil. Shea is a nutritional and economic resource for women across Africa, providing an annual bounty of fruit, food-oil and cash income for an estimated 10 million households over a wide geographic range from eastern Senegal to northern Uganda (Naughton 2015). Shea timber is of good quality, termite resistant and generally very durable but is normally used only when the tree has passed the fruit-bearing age (Joker 2018 c). Moreover, shea tree is an important source of honey, assuring a good supply of nectar and pollen (Lassen et al 2016). Another food product provided by the shea tree is the protein-rich caterpillar, Cirina butyrospermii, produced in many parts of the shea belt (Ky-Dembele et al 2021, Boffa 2015). These caterpillars are eaten across the West African region. Harvested at the larva stage, caterpillars are an important source of nutrition and income for many subsistence farming households in the region.

Silvicultural features:

Vitellaria paradoxa is a key economic fruit tree species that is very abundant across a 5,000km wide belt of savanna between the equatorial rain forest and the Sahel zone bordering the Sahara (Hall et al 1996, Boffa 2015). Its natural range extends across 21 countries, from the eastern part of Senegal and Gambia to the high plateau of East Africa into south-eastern Uganda forming an almost unbroken belt, 5000 km long and averaging 500 km wide (Sanou and Lamien 2011, Bouvet et al 2004). Within the species, two subspecies have been distinguished, *V. paradoxa* subsp. *paradoxa* and subsp. *nilotica* (Boffa 2015, Hall et al 1996, Bouvet et al 2004).

The subspecies paradoxa occurs at altitudes between 100 m and 600 m above sea level with mean annual rainfall of between 600 mm and 1400 mm. Stands of subsp. *nilotica* occur at higher altitudes between 650 m and 1600 m with mean annual rainfall ranging between 500 mm and 1500 mm. Shea can grow on a variety of soil types (Joker 2018c), but also well adapted to poor shallow soils and land suitable for rainfed crops. Shea trees are more vigorous on deep alluvial soils (Boffa 2015).

The best growth is obtained on farmed land where trees benefit from enough protection against bush fires and livestock. Shea parklands are mainly established through natural regeneration. However, shea planting is taking a further step forward and although tree growth from seed is slow, seedling production techniques in the nursery have been developed (Kalinganire et al 2008), and alternatively through direct seeding in large holes (Ky-Dembele et al 2022). The seeds have no dormancy, therefore no pretreatment required. However, the pulp should always be removed before sowing (Joker 2018c), and seeds should be sown shortly after harvest. Vegetative propagation is recommended to capture the best genotypes of the species and for early fruiting (see Figure 5.12). Grafting is shortening the juvenile phase of tree, making fruiting from 20 years to 2 years after planting. Vegetative propagation of shea trees does help the cultivation of superior high-yielding and early maturing types. Stem cuttings, air layering, grafting and micropropagation techniques of shea have been developed (Sanou et al 2003,

The seeds have no dormancy, therefore no pretreatment required. However, the pulp should always be removed before sowing (Joker 2018c), and seeds should be sown shortly after harvest. Vegetative propagation is recommended to capture the best genotypes of the species and for early fruiting (see Figure 5.12).

Grafting is shortening the juvenile phase of tree, making fruiting from 20 years to 2 years after planting. Vegetative propagation of shea trees does help the cultivation of superior high-yielding and early maturing types. Stem cuttings, air layering, grafting and micropropagation techniques of shea have been developed (Sanou et al 2003, Boffa 2015). Apart from grafting, other methods cannot be easily implemented on a large scale by farmers. Grafting in the nursery and/or grafting on shea wildings in farmers' fields, has been successfully implemented by smallholders and communities in West Africa (refer to Figure 5.13). On farmers' fields, side cleft and side tongue grafting methods gave more than 80% success rates (Sanou et al 2003). Regarding growth, results from an 8-year old provenance/ plantation in Gonse (Burkina Faso) showed an annual height increment of 0.35 m (Bayala et al 2009).

Figure 5.12: A 9-year old shea tree plantation at Kledu Farm, Bangineda, Mali (Source: Antoine Kalinganire CIFOR-ICRAF Mali Office).

In Mali, results from an 8-year old provenance/plantation in Gonse (Burkina Faso) showed an annual height increment of 0.35 m (Bayala et al 2009). In Mali, an initial increment of more than 0.7cm has been recorded in a plantation at Tieman-Baguineda, Mali (Antoine Kalinganire, Personal Observations). Grafted and irrigated individuals in Samanko, Mali recorded an annual height increment of more than one meter, four years after planting (Antoine Kalinganire, Personal Observations).

Pests and diseases:

Shea is vulnerable with hemi-parasitic plants (*Loranthaceae*), including mistletoe parasites: *Agelanthus dodoneifolius, Tapinanthus globiferus* and *T. ophiodes*. Shea vulnerability to fungal diseases is low (Boffa 2015). Seeds in the nursery are often eaten by rodents.

Limitations:

It does not do well in flooded areas, and on highly sandy or clayish soils.

5.12 SCELEROCARYA BIRREA (A. RICH.) HOCHST MARULA (ENG), PRUNIER D' AFRIQUE (FRENCH)

The species:

Sclerocarya birrea (A. Rich.) *Hochst. Anacardiaceae* Family. Synonyms: *Commiphora subglauca Engl., Poupartia birrea* (*A.Rich.*) *Aubrev., Sclerocarya caffra Sond., Spondias birrea A. Rich.*

Main attributes and utilisation:

Sclerocarya birrea subsp. *birrea* plays a very significant role in the diet and culture of people in many countries in the Sahel (Muok et al 2011, Teklehaimanot 2008, Hall et al 2002). The marula is a valued fruit tree and all parts of the fruit are edible. Ripe fruit can be eaten fresh. Both the pulp and kernel are nutritious. The kernels yield oil that is useful for cooking and for manufacturing cosmetics. The juicy pulp is rich in vitamin C (Joker 2018d, Jaenicke and Thiong'o 2000). It is used in jams and jellies, sweets, alcoholic beverages (beer, wine and liqueurs) (Muok et al 2011, Hall et al 2002). Almost all parts of the plant, but especially the bark and leaves, are used for various medicines (Muok et al 2011, Burkill 1985). The wood is used for carvings and fuel, fibres from the inner bark for making rope, fruits and leaves are a source of fodder (Joker 2018d). Branches are lopped for animal fodder in times of drought.

Silvicultural features:

Sclerocarya birrea occurs through west, north-east and east tropical Africa. Across a range of vegetation types, principally mixed deciduous woodland, wooded grassland and through the open dry savannahs of northern tropical Africa and the Sahel (Joker 2018d, Hall et al 2002). It prefers well drained sandy soils and loams but is often found growing on rocky hills. The soil where trees are planted should be at least 3m deep. Occurs at low to medium altitudes in areas with 200-1600 mm rain per year. Plantation seedlings are mainly produced through seeds in the nursery. The hard endocarp (stone) forms a physical barrier to seed germination and removal of the opercula will improve germination (Hall et al 2002). If the opercula have been removed, germination is fast and uniform, reaching 85% after two weeks from sowing. Soaking in cold water for 24h may increase germination.

Figure 5.13: A 15-year old Screlocarya birrea tree grown in Samanko, Mali (Source: Antoine Kalinganire CIFOR-ICRAF Mali Office).

Vegetative propagation with cuttings has proven successful. Grafting is successful- tongue, top and side grafting methods were very successful (Soloviev et al 2004). Top wedge grafting can be carried out on established young trees in the field or on raised seedling rootstocks. Trees are planted during rainy season. Planting holes should be large with a minimum of 89 cm wide and square, as round holes encourage roots to grow in a cycle causing poor anchorage (Hall et al 2002). Young seedlings can survive drought. Growth in plantations is slow with about 0.5 m annual height growth per year during the first 5 years. Compost or manure should be used during the first year of planting applied at the start and at the end of the rainy season. Moreover, irrigation, water should be supplied every two weeks to each tree, except during rainy season. The species needs direct sunlight to grow and for the fruit to ripen and trees should be grown under such conditions (Hall et al 2002).

Protection from wind is equally important because strong winds can break shoots, dry out new leaves, reduce or arrest growth and blow flowers and fruits off the trees.

Pests and diseases:

Seedlings are sensitive to damping off and root collar restriction caused mainly by fungal attacks. The species is susceptible to a variety of pests and diseases.

Limitations:

Sclerocarya birrea grows in a range of soil types, but does not flourish where drainage is poor (Hall et al 2002). As stated by Muok et al (2011), unmonitored harvesting of bark for medicines and wood for carving and firewood may impact negatively on both the individual tree and the entire species population.

5.13 ZIZIPHUS MAURITIANA LAM. JUJUBIER, POMME DU SAHEL (FRENCH), BER (ENGLISH).

The species:

Ziziphus mauritiana Lam. Rhamnaceae Family. Synonyms: Rhammus jujuba L., Ziziphus jujuba (L.) Lam., Z. jujuba (L.) Gaertn. (including var. *stenocarpa* Kuntze), *Z. tomentosa Poir., Z. rotundata D.C., Z. aucheri Boiss., Z. insularis Smith, Z. sororia Roem.* and *Schult., Z. orthacantha DC.*

Main attributes and utilisation:

A multipurpose tree that provides both fruit, fodder and fuel (Joker 2018e). Ber is an important fruit in sub-Saharan Africa contributing to food security and household income. The main product from ber is the fruit pulp which is consumed fresh/raw or dry and made into a juice. In addition, leaves are used for fodder and the leaves, roots and bark are used for medicinal purposes.

The wood is used for handles, kitchen utensils, firewood and charcoal (Arbonnier 2000). The main uses for ber are delicious fruits consumed fresh or dry. Fruit has a high sugar content and high levels of vitamin C, phosphorous and calcium (Kalinganire and Brehima 2011, Teklehaimanot 2008). The fruit pulp is used for the extraction of delicious juice. Oil is also extracted from the seeds. The leaves are used as forage for cattle, sheep and goats. Leaves are used for fodder and together with roots and tree bark for medicinal purposes. The thorny tree makes excellent fencing, and is also planned for erosion control, soil and river-bank stabilization.

Silvicultural features:

Ber is widely distributed throughout the warm subtropics and tropics of South Asia and Africa. It is found in the arid to semi-arid zones of all Sahelian countries in West Africa, and of East and southern Africa (Sudan and Kenya to Mozambique and Angola) (Kalinganire and Kone 2011, Arbonnier 2000). In West African Sahel, although *Ziziphus mauritiana* was ranked as one of the most preferred fruit tree species, its fruits are very small whereas farmers are most interested in Indian and Thai varieties producing big and tasty fruits (see Figure 5.15).

Ber is most abundant in savannah parklands in semi-arid lowlands with an annual rainfall up to 800 mm and maximum temperatures up to 50°C. It is a drought tolerant species but also cultivated in higher rainfall areas. It grows on a wide range of sites but prefers free-draining soils, though it tolerates short-term water logging and withstands salinity (Joker 2018e). It is growing up to 1500m altitude.

Rural farmers rank it as one of the most preferred fruit tree species and the local populations are managed in the wild. However, farmers are more interested in Indian and Thai varieties that produce larger and tastier fruits than African varieties. These are mostly managed in fruit orchards.

The species is propagated by seed grown in the nursery or by direct sowing in large holes. The hard stone restricts germination and cracking the shell or extraction of seeds fastens germination (Joker 2018e). Before sowing, the seeds are soaked in cold water for two days. Seeds need light to germinate. Horticultural cultivars are normally grafted onto wild type seedling root stocks either in the nursery or in the field (Joker 2018e, Kone et al 2009). Grafted plants start fruit production 3 months after planting compared to 6 years for non-grafted local plant materials.

The introduced cultivars performed better than the local cultivars (Ouedraogo et al 2006). Grafted individuals are having an initial fast growth with a mean height growth of more than 1.5 m for 3 months old plants (Rabiou et al 2017).

Local ber accessions commonly produce about 5-8 kg of fruit per tree at three years of age, without irrigation or fertilizer, compared with 20-50 kg per tree for improved varieties from India and Thailand (Tougiani et al 2017, Kone et al 2009). With irrigation and improved management fruit yields of 80-200 kg per tree are achievable. Irrigation and rock phosphate have a positive effect on growth and fruit production.

Figure 5.14: Fruit production of Ziziphus mauritiana orchard at Sadore, Niger (Source: Antoine Kalinganire, CIFOR-ICRAF Mali Office).

Pests and diseases:

Indian varieties of ber are attacked by fruit borers, fruit flies and leaf and fruit eaters. The variegated grasshopper (*Zonocerus variegatus L.*) is one of the major pests, and limits cultivation of most improved varieties in sub-Saharan Africa. The fresh fruit of improved varieties also deteriorates very rapidly after harvest, making transport to the markets difficult.

Limitations:

Farmers face many constraints to cultivation, including the limited productivity of local accessions, limited water availability, infertile soils, threats from pests and diseases, lack of improved germplasm and/or lack of access to the improved germplasm, limited knowledge regarding fruit tree management, and natural resources policies that often prevent farmers from managing trees on their farms.

6. THE WAY FORWARD

To enhance farmers' participation in the planting of improved planting stock of priority indigenous fruit trees, the farmers need good access to these improved tree germplasms. The current systems of forest seed and seedling distribution to farmers remain a major constraint. Smallholders are planting some indigenous tree species, but the genetic quality of the material is often poor, and good planting material is not available. Moreover, along with improved tree cultivation techniques, there is a need to have improved access to markets of tree products. To increase farmers' income from the fruits of indigenous trees and other wood and non-wood products, appropriate processing technologies for the products need to be developed to add value to the products.

There is no one-size-fits-all approach that will advance the growing of indigenous trees across the west African drylands. However, coupling the best practices/approaches and the best germplasm would enhance the planting of indigenous trees in different Sahelian contexts.

Actions for promoting tree planting by communities and growers will be effective only if such programs meet the priorities of the beneficiaries and linking them to the local, regional and international markets of tree products. Sustained productivity is key for the success of growing native trees in the Sahel by smallholders and growers. As discussed in the report, sustained productivity would be supported by the best practices, good management and clear links along the tree value-chain. Unsustainable practices and poor management of the tree planting undermine all values, including an intensive growing of native trees in-lieu of exotics.

The so-called fast-growing tree species will not grow at fast rates unless they are planted on suitable sites with the right germplasm and managed properly to promote growth.

Despite the importance of productivity for the native trees in the Sahel, the report gives less information on growth and yield at all levels that can be used to help tree growers. Therefore, it is recommended to further invest on applied research for managing tree productivity through domestication, long-term assessments, and encouraging and supporting (training and demonstration woodlots) communities and growers in tree planting with indigenous tree species.

7. REFERENCES

Abebe T. 1994. Growth performance of some multi-purpose trees and shrubs in the semi-arid areas of Southern Ethiopia. Agroforestry Systems. 26 (3): 237-248.

Abdou-Habou MK, Rabiou H, Abdou L, Mamoudou BM, Yandou IB, Mahamane A. 2019. Vegetative propagation of Balanites aegyptiaca (L.) Del. by air layering under Sahelian climate in Niger. Asian Journal of Research in Agriculture and Forestry 3(4):1-10.

Ahoton LE, Adjakpa JB, M'po MI, Akpo EI. 2009. Effet des prétraitements des semences sur la germination de Prosopis africana (Guill., Perrot. et Rich.) Taub., (Cesalpiniacees). Tropicultura 27(4):233-238.

Andary C, Doumbia B, Sauvan N, Olivier M, Garcia M (2005). Anogeissus leiocarpa (DC.) Guill. and Perr. In: Jansen, P.C.M. and Cardon, D. (Editors). PROTA 3: Dyes and tannins/ Colorants et tanins [CD-Rom]. PROTA, Wageningen, Netherlands, p. 13.

Arbonnier M. 2000. Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest (2nd ed.). Montpellier, France. CIRAD, MNHN, UICN. 542 p.

Assogbadjo AE, Chadare FJ, Glele Kakai R, Fandohan B, Baidu-Forson JJ. 2012. Variation in biochemical composition of baobab (Adansonia digitata) pulp, leaves and seeds in relation to soil types and tree provenances. Agriculture, Ecosystems and Environment, 157 :94-99.

Aubréville A. 1950. Flore Forestière Soudano-Guinéenne, Géographiques, Maritimes et Coloniales 17, Rue Jacob (VI), Paris, 523 p.

Bakhoum D, Fall F, Diouf AM, Hirsch D, Balachandar D, Diouf D. 2018. Senegalia senegal (synonym: Acacia senegal), its importance to sub-Saharan Africa, and its relationship with a wide range of symbiotic soil microorganisms. South African Journal of Botany, 1119: 362-368. https://doi.org/10.1016/j.sajb.2018.10.007

Barnekow Lilleso JP. 2012. Sustainable germplasm distribution strategies. In: Dawson I, Harwood C, Jamnadass R, Beniest J (eds) Agroforestry tree domestication: a primer. The World Agroforestry Centre, Nairobi, Kenya. pp. 128-133.

Bationo BA, Ouédraogo SJ, Guinko S. 2001. Stratégies de régénération naturelle de Detarium microcarpum Guill. et Perr. dans la forêt classée de Nazinon (Burkina Faso). Fruits 56: 271–285.

Bayala J, Ouedraogo SJ, Ong CK 2009. Early growth performance and water use of planted West African provenances of Vitellaria paradoxa C.F. Gaertn (Karite) in Gonse, Burkina Faso. Agroforest Syst 75:117-127.

Bellefontaine R, Malagnoux M, Ichaou A. 2012. Techniques forestières et innovations dans les opérations de reboisement. In : A. Dia, R. Duponnois (Eds.), La Grande Muraille Verte : Capitalisation des recherches et valorisation des savoirs locaux, Marseille : IRD. https://doi.org/10.4000/books.irdeditions.3247

Bernard NB, Latif IN, Adnan S, Hamza I, William JA. 2019. Effect of seed pre-treatment and its duration on germination of Detarium microcarpum (Guill. and Perr.). African Journal of Environmental Science and Technology 13(8): 317-323.

Boffa J-M. 2015. Opportunities and challenges in the improvement of the shea (Vitellaria paradoxa) resource and its management. Occasional Paper 24. Nairobi: World Agroforestry Centre.

Bosch CH, Sié K, Asafa BA. 2004. Adansonia digitata L. Record from Protabase. In: Grubben GJH, Denton OA (Eds.), Plant resources of tropical Africa. Wageningen. The Netherlands.

Botoni E, Larwanou M, Reij C. 2010. La régénération naturelle assistée (RNA) : Une opportunité pour reverdir le Sahel et réduire la vulnérabilité des populations rurales. IRD Éditions, p. 151–162.

Bouvet J-M, Fontaine H, Sanou H, Cardi C. 2004. An analysis of the pattern of genetic variation in Vitellaria paradoxa using RAPD markers. Agroforestry Systems 60: 61-69.

Burkill HM. 1985. The useful plants of west tropical Africa, 2nd edn, ol. 1. Royal Botanic Gardens, Kew. 960 pp.

Catterall CP. 2020. Influencing landscape-scale revegetation trajectories through restoration interventions. Curr. Landsc. Ecol. Rep. doi: 10.1007/s40823-020-00058-5

CBD. 2010. The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets. UNEP/CBD/COP/DEC/X/2. Nairobi: CBD.

Chazdon RL, Guariguata MR. 2016. Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. Biotropica 48, 716–730. doi: 10.1111/btp.12381

Chomba S, Sinclair F, Savadogo P, Bourne M, Lohbeck M. 2020. Opportunities and constraints for using Farmer Managed Natural Regeneration for land restoration in Sub-Saharan Africa.

Front. For. Glob. Change 3:571679. https://doi.org/10.3389/ffgc.2020.571679

Cronquist A. 1988. The evolution and classification of flowering plants. Allen Press, Kansas, p 555.

Cuny P, Kouyate AM. 1998. Recherche forestière participative sur les espèces locales au sud du Mali. Journal Forestier Suisse 149 (3) :169-182.

Dayamba SD, Tigabu M, Sawadogo L, Oden PC. 2008. Seed germination of herbaceous and woody species of the Sudanian savanna-woodland in response to heat chock and smoke. Forest Ecology and Management 256(3): 462470.

Dembele IC. 2012. Etude préliminaire du potentiel de multiplication par bouture de l'Anogeissus leiocarpus (DC.) Guill. et Perr. au Mali. Influence de l'état physiologique des boutures et des régulateurs de croissance.

Mémoire présenté à la faculté des études supérieures et postdoctorales de l'Université Laval pour l'obtention du grade de Maitrise ès Sciences (M.Sc). Université Laval, Québec.

Diallo AM, Kjær ED, Ræbild A, Petersen KK, Nielsen LR. 2016. Polyploidy can confer superiority to West African Acacia senegal (L) Willd. Trees. Frontiers in Plant Science. doi: 10.3389/fpls.2016.00821.

Diatta O, Sarr MS, Hansen JK, Diallo AM, Nielsen LR, Raebild A and Kjaer ED. 2021. Survival and growth of Acacia senegal (L.) Wild. provenances in Senegal: the importance of genotype by environment interactions. Annals of Forest Science Journal 78(4). DOI: 10.1007/s13595-021- 01098-5

Di Sacco A, Hardwick KA, Blakesley D, Brancalion PHS, Breman E, Cecilio-Rebola L, Chomba S, Dixon K, Elliott S, Ruyonga G, et al. 2021. Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. Glob. Change Biol. 27: 1328–1348. https://doi.org/10.1111/gcb.15498.

Diop AG, Sakho M, Dornier M, Cisse M, Reynes M. 2005. Le baobab Africain (Adansonia digitata L.) : principales caractéristiques et utilisations. Fruits 61:55-69.

Duguma L, Minang P, Betemariam E, Carsan S, Nzyoka J, Bah A, Jamnadass R. 2020. From tree planting to tree growing: Rethinking ecosystem restoration through trees. World Agroforestry (ICRAF) Working Paper No 304. Nairobi, Kenya

El-Siddig K, Gunasena HPM, Prasad BA, Pushpakumara DKNG, Ramana KVR, Viyayanand P, Williams JT. 2006. Tamarind – Tamarindus indica L. Southampton Centre for Underutilised Crops, Southampton, UK.

Etongo D, Djenontin INS, Kanninen M, Fobissie K. 2015. Smallholders' tree planting activity in the Ziro Province, Southern Burkina Faso: Impacts on livelihood and policy implications. Forests 6:2655-2677.

Evans J, Turnbull JW. 2004. Plantation forestry in the tropics: The role, silviculture, and use of planted forests for industrial, social, environmental, and agroforestry purposes. Oxford University Press.

Fagg CW, Allison GE (Eds.). 2004. Acacia senegal and the gum Arabic trade, Oxford Forestry Institute, Department of Plant Sciences, University of Oxford, Oxford.

FAO. 2020. Évaluation des ressources forestières mondiales 2020 - Principaux résultats. Rome. https://doi.org/10.4060/ca8753fr

FAO. 2006. Global forest resource assessment 2005. Food and Agriculture Organization of the United Nations, Rome.

Faye MD, Weber JC, Abasse TA, Boureima M, Larwanou M, Bationo AB, Diallo BO, Sigue H, Dakouo J-M, Samake O, Sonogo Diaite D. 2011. Farmers' preferences for tree functions and species in the West African Sahel. Forests Trees Livelihoods 20:113–136

Felber R, Diallo OI. 1991.Un programme de recherche en foresterie paysanne dans le sud du Mali : présentation et premiers résultats. Journal Forestier Suisse 142: 983-998

Gauove OG, Ticktin T. 2008. Impacts of bark and foliage harvest on Khaya senegalensis (Meliaceae) reproductive performance in Benin. Journal of Applied Ecology 45: 35-40.

Gebauer J, Yahia O. Adam YO, Sanchez AC et al. 2016. Africa's wooden elephant : the baobab tree (Adansonia digitata L.) in Sudan and Kenya : a review. Genet Resour Crop Evol 63: 377- 399.

Gonzalez P, Tucker CJ, Sy H. 2012. Tree density and species decline in the African Sahel attributable to climate. J. Arid Environ. 78, 55–64. doi:10.1016/j.jaridenv.2011.11.001

Hall JB, O'Brien EM, Sinclair FL. 2002. Sclerocarya birrea: a monograph. School of Agricultural and Forest Sciences Publication No. 19. University of Wales, Bangor, UK. 157pp.

Hall JB, Tomlinson HF, Oni PI, Buchy M, Aebischer DP. 1997. Parkia biglobosa: A Monograph. School of Agricultural and Forest Sciences, University of Wales, Bangor, UK.

Hall JB, Aebischer DP, Tomlinson HF, Osei-Amaning E, Hindle JR. 1996. Vitellaria paradoxa: A Monograph. School of Agricultural and Forest Sciences Publication No. 8. University of Wales, Bangor, UK.

Hall JB, Walker D. 1991. Balanites aegytiaca: a Monograph. School of Agricultural and Forest Sciences. University of Wales, Bangor, UK.

Holl KD, Brancalion HS. 2022. Which of the plethora of tree-growing projects to support? One Earth (2022), https://doi.org/10.1016/j.oneear.2022.04.00

Holl KD, Brancalion PH. 2020. Tree planting is not a simple solution. Science 368, 580–581. doi: 10.1126/science.aba8232

Houndonougbo JSH, Kassa B, Mensah S., Salako V K, Glèlè Kakaï R, Assogbadjo A E. 2020. A global systematic review on conservation and domestication of Parkia biglobosa (Jacq.) R. Br. ex G. Don, an indigenous fruit tree species in Sub-Sahara African traditional parklands: current knowledge and future directions. Genetic Resources and Crop Evolution 67(4): 1051-1066.

Jaenicke H, Thiong'O MK. 2000. Preliminary nutritional analysis of marula (Sclerocarya birrea) fruits from two Kenyan provenances. Acta Horticulturae 531:245-249.

Joker D. 2018a. Acacia Senegal (L.) Willd. Seed Leaflet no. 5. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Joker D. 2018b. Tamarindus indica (L.) Seed Leaflet no. 45. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Joker D. 2018c. Vitellaria paradoxa Gaertn.f. Seed Leaflet no. 50. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Joker D. 2018d. Sclerocarya birrea (A. Rich.) Hochst. Seed Leaflet no. 72. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Joker D. 2018e. Ziziphus mauritiana Lam. Seed Leaflet no. 85. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Joker D, Gamene S. 2018. Khaya senegalensis (Desr.) A.Juss. Seed Leaflet no. 66. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Kalinganire A, Kone B. 2011. Ziziphus mauritiana, ber. Conservation and Sustainable Use of Genetic Resources of Priority Food Tree Species in sub-Saharan Africa. Bioversity International (Rome, Italy)

Kalinganire A, Dembele SG, Sanogo K, Kone B, Arinloye D. 2020a. Manual on Environmental Education Modules in Mali. World Agroforestry (ICRAF) – Scaling up Climate Friendly Agroforestry Technologies in Mali (SmATScaling) Report to Feed The Future – USAID Mali.

Kalinganire A, Kone B, Savadogo P, Arinloye AADD, Ky-Dembele C. 2020b. Influence of honey bees on fruit-set and production of shea trees (Viterallia paradoxa) in the Sahelian parklands. Occasional Paper No. 28. Nairobi: World Agroforestry.

Kalinganire A, Savadogo P, Ky-Dembele C, Bush D, Raebild A, Tougiani A, Muchugi A, Fatoumata TT, Kone B. 2022. Evidence of early genetic variation in survival and growth traits of baobab (Adansonia digitata L.) – the way forward for domestication and breeding. Agroforest Sys.

Kalinganire A, Weber JC, Uwamariya A, Kone B. 2008. Improving rural livelihoods through domestication of indigenous fruit trees in parklands of the Sahel. In: Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P and Kwesiga F (eds.). Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization. CABI International Publishing, Oxfordshire, pp.186-203.

Kambou S. 1997. Etude de la biologie de la reproduction de Anogeissus leiocarpus (DC.) Guill. et Perr. Combretaceae) au Burkina Faso. Thèse de Doctorat d'Etat, Université de Ouagadougou, Burkina Faso. 172p.

Kelly BA. 2011. Growth response of Anogeissus leiocarpa coppices to prescribed fire and weeding after plantation harvesting in the Sudanian zone of Mali, West Africa. African Journal of Plant Science 5(2):92-101.

Kelly BA, Sanogo S, Sidibe SI, Ceci P, Castillo-Lorenzo E, Ulian T. 2021a. Survival and growth of Adansonia digitata L. tall bare roots in farm fields: a case study from Bankass, Mali (West Africa). Environment, Development and Sustainability https://doi.org/10.1007/s10668-021- 01768-4

Kelly BA, Kouyate AM, Dembele SG. 2021b. Variation of Parkia biglobosa morphological traits according to land use and agro-climatic zones in southern Mali. African Journal of Plant Science 15(1):20-27.

Kelly BA, Cuny P. 2000. Plantations d'espèces forestières locales sur sols hydromorphes. Bilan d'une expérimentation sylvicoles au Sud du Mali. Chronique Internationale. Rev. For. F. 5-2000.

Kone B, Kalinganire A, Doumbia M. 2009. La culture du jujubier : un manuel pour l'horticulteur sahélien. ICRAF Technical Manual no. 10. Nairobi: World Agroforestry Centre

Kouyaté AM, Lankoandé B, Ouédraogo A, Diarra I, Coulibaly HT, Lykke AM. 2015. Techniques de propagation de Balanites aegyptiaca. Fiche technique. Projet QualiTree

Kouyaté AM, Guindo F, Diawara H, Diarra I, Van Damne P. 2012. Evaluation du comportement de Detarium microcarpum arrosé en plantation. Les Cahiers de l'Economie Rurale, 14 : 63-74.

Kouyaté AM. 2005. Aspects ethnobotaniques et étude de la variabilité morphologique, biochimique et phénologique de Detarium microcarpum Guill. & Perr. au Mali. Thèse présentée pour l'obtention du grade de Docteur (PhD) en Biosciences Ingénieurs – Agronomie- Université de Gand, Belgique. 190p.

Kouyaté AM, Van Damme P, Diawara H. 2006. Evaluation de la production en fruits de Detarium microcarpum Guill. & Perr. au Mali. Fruits 61(4): 267-273.

Ky-Dembele, C, Keita, MK, Traore, FT. et al. 2022. Direct seeding of six agroforestry tree species indigenous to the Sahel: the effect of fungicide and planting-hole depth on seed germination and seedling emergence capacity. Agroforest Syst (2022). https://doi.org/10.1007/s10457-022-00752-9

Ky-Dembele C, Bayala J, Boffa JM, Kalinganire A, Minang PA. 2021. Shea tree crop management in West Africa. In: Minang PA, Duguma LA, van Noordwijk M, eds. 2021. Tree Commodities and Resilient Green Economies in Africa. Nairobi, Kenya: World Agroforestry (ICRAF).

Ky-Dembele C, Dayamba SD, Savadogo P, Kalinganire A, Bayala J, Muchugi A, Ramni J. 2019. Land use dictates diversity, density and regeneration of woody species in Southwestern Mali, West Africa. Tropical Ecology 60: 114-128.

Ky-Dembele C, Tigabu M, Bayala J, Ouedraogo SJ, Oden PC. 2008. Comparison between clonal and sexual plantlets of Detarium microcarpum Guill. & Perr., a savanna tree species in Burkina Faso. African Journal of Ecology 46(4): 602–611.

Ky-Dembele C, Tigabu M, Bayala J, Savadogo P, Boussim IJ, Oden PC. 2010. Clonal propagation of Detarium microcarpum from root cuttings. Silva Fennica. 44(5): 775-786.

Lamien N, Ekué M, Ouedraogo M, Loo J. 2011. Parkia biglobosa, néré. Conservation et utilisation durable des ressources génétiques des espèces ligneuses alimentaires prioritaires de L'Afrique subsaharienne. Bioversity International (Rome, Italie).

Laouali A, Saley K, Rabiou H, Ali M. 2015a. Vegetative Propagation Trial of Prosopis africana (Guill. et Perr.) Taub. by Air Layering under Sudano-Sahelian Climate in the South-Central Niger. Journal of Botany, vol. 2015, Article ID 286582, 6 pages, 2015. https://doi.org/10.1155/2015/286582

Laouali A, Iro DG, Abdoullatif YT, Habou R, Mahamane A. 2015b. Etude de la germination de la graine et suivi de la croissance en pépinière de Proposis africana (G. et Perr.) Taub., espèce menacée de disparition au Niger. Annales de l'Université Abdou Moumouni, Tome XVII-A, PP. 1-12.

Lassen K, Nielsen L, Lompo D, Dupont Y, Kjær E. 2016. Honey bees are essential for pollination of Vitellaria paradoxa subsp. paradoxa (Sapotaceae) in Burkina Faso. Agroforest Sys 92: 23-34.

Leakey RRB, Newton AC (eds) 1994. Domestication of tropical trees for timber and non-timber products. MAB Digest 17, UNESCO, Paris.

Louppe D, Ouattara N.1996. Résultats des mensurations - Campagne de 1996. Korhogo (Côte d'Ivoire) : IDEFOR, 1996. 54 p.

Lyam PT, Duque-Lazo J, Durka W, Hauenschild F, Schnitzler J, Michalak I, et al. 2018. Genetic diversity and distribution of Senegalia senegal (L.) Britton under climate change scenarios in West Africa. PLoS ONE 13(4): e0194726. https://doi.org/10.1371/journal.pone.0194726.

Maisharou A, Chirwa PW, Larwanou M, Babalola F, Ofoegbu C. 2015.Sustainable land management practices in the Sahel: review of practices, techniques and technologies for land restoration and strategy for up-scaling. Int For Rev 17:1–19

Maranz S, Niang A, Kalinganire A, Konaté D, Kaya B. 2008. Potential to harness superior nutritional qualities of exotic baobabs if local adaptations can be conferred through grafting. Agroforest Sys 72: 231-239.

Maranz S, Kpikpi W, Wiesman Z, De Saint Sauveur A, Chapagain B. 2004. Nutritional values and indigenous preferences for shea fruits (Vitellaria paradoxa C.F. Gaertn F.) in African agroforestry parklands. Economic Botany 58:588-600.

Maundu PM, Ngugi GW, Kabuye CHS. 1999. Traditional Food Plants of Kenya. National Museums of Kenya, Nairobi, Kenya.

Maydell HJ von. 1986. Arbres et arbustes du Sahel : leurs caractéristiques et leurs utilisations. Ed-GTZ, Eschborn, 532p.

Muchugi A, Kalinganire A, Chege J, Nyoka I. 2021. Commodity tree crop planting material infrastructures in Africa. In: Minang PA, Duguma LA, van Noordwijk M, eds. 2021. Tree

commodities and resilient green economies in Africa. Nairobi, Kenya: World Agroforestry (ICRAF).

Muok BO, Khumalo SG, Tadesse W, Alem Sh. 2011. Sclerocarya birrea, Marula. Conservation and Sustainable Use of Genetic Resources of Priority Food Tree Species in sub-Saharan Africa. Bioversity International (Rome, Italy)

Mwaura L, Dawson I. 2012. Seed procurement practices. In: Dawson I, Harwood C, Jamnadass R, Beniest J (eds) Agroforestry tree domestication: a primer. The World Agroforestry Centre, Nairobi, Kenya. pp. 94-101.

Nagarajan B, Nicodemus A, Mandal AK, Verma RK, Gireesan K, Mahadevan NP. 1998. Phenology and controlled pollination studies in Tamarind. Silvae Genetica 47: 237-241.

Nambiar EKS. 2021. Small forest growers in tropical landscapes should be embraced as partners for Green-growth: Increase wood supply, restore land, reduce poverty, and mitigate climate change. Trees, Forests and People 6: 100154.

Naughton C, Lovett P, Mihelcic J. 2015. Land suitability modeling of shea (Vitellaria paradoxa) distribution across sub-Saharan Africa. Applied Geography 58:217-227.

Nikiema A. 2005. Agroforestry parkland species diversity: uses and management in semi-arid West-Africa (Burkina Faso). University of Wageningen, Wageningen, p 102.

Nikiema, A. 2001. Promoting Indigenous Tree Species Plantation in the Sahel, with Special Reference to Burkina Faso. In: Pasternak, D., Schlissel, A. (eds.) Combating Desertification with Plants. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-1327-8_41

Nkonya E, Mirzabaev A, von Braun J. (eds). 2016. Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Cham: Springer.

Nyoka BI, Roshetko J, Jamnadass R, Muriuki J, Kalinganire A, Lillesø JP, Beedy T, Cornelius J. 2015. Tree seed and seedling supply systems: a review of the Asia, Africa and Latin America models. Small-scale Forestry 14(2):171-191.

Okunlola AI, Adebayo RA, Orimogunje AD. 2011. Methods of breaking seed dormancy on germination and early seedling growth of African locust bean (Parkia biglobosa) (Jacq.) Benth. Journal of Horticulture and Forestry, 3(1):1-6.

Oliet J, Artero F, Puértolas J, Grau J, Tavira S, Luna Ramos L. 2012. Deep planting with shelters improves performance of different stocktype sizes under arid Mediterranean conditions. New For 43:925–939. https://doi.org/10.1007/s11056-012-9345-5

Opuni-Frimpong E, Tekpetey SL, Owusu SA, Obiri BD, Appiah-Kubi E, Opoku S, Nyarko- Duah NY, Essien C, Opuku EM, Storer AJ. 2016. Managing mahogany plantations in the tropics. Field Guide for Farmers. CSIR-FORIG, Kumasi, Ghana. Vii+95pp.

Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S. 2009. Agroforestree database: a tree reference and selection guide version 4.0. http://www.worldagroforestry.org/sites/treedbs/treedatabases.

Ouedraogo SJ, Bayala J, Dembele C, Kabore A, Kaya B, Niang A, Some AN. 2006. Establishing jujube trees in Sub-Saharan Africa: response of introduced and local culivars to rock phosphate and water supply in a peri-urban garden in Burkina Faso, West Africa. Agroforest Syst 68:69:80.

Ouedraogo AS. 1995. Parkia biglobosa (Leguminosae) en Afrique de l'Ouest. Biosystematique et amelioration. PhD thesis, Institute of Forestry and Natural Resources, Wageningen, The Netherlands.

Padgham J, Abubakari A, Ayivor et al. 2015. Vulnerability and adaptation to climate change in the semi-arid regions of West Africa. ASSAR Working Papers. International Development Research Centre. Ottawa, Canada.

Parkouda C, Sanou H, Tougiani A, Korbo A, Nielsen DS, Tano-Debrah K, Raebild A, Diawara B, Jensen JS. 2012. Variability of baobab (Adansonia digitata L) fruits' physical characteristics and nutrient content in the West African Sahel. Agroforest Syst 85:455-463.

Pasiecznik NM, Felker P, Harris PJC, Harsh LN, Cruz G, Tewari JC, Cadoret K, Maldonado LJ. 2004. The Prosopis juliflora –Prosopis pallida complex: a monograph. Henry Doubleday Research Association, Coventry.

Raddad EAY, Salih AA, Fadl MAE, Kaarakka V, Luukkanen O. 2005. Symbiotic nitrogen fixation in eight Acacia senegal provenances in dryland clays of the Blue Nile Sudan estimated by the 15N natural abundance method. Plant Soil 275(1–2):261–269. https://doi.org/10.1007/s11104-005-2152-4

Ræbild A, Hansen UB, Kambou S. 2012. Regeneration of Vitellaria paradoxa and Parkia biglobosa in a parkland in Southern Burkina Faso. Agroforest Syst 85, 443–453 (2012). https://doi.org/10.1007/s10457-011-9397-0

Raebild A, Graudal L, Ouedraogo LG. 2003. Evaluation of a provenance trial of Acacia senegal at Gonse, Burkina Faso. Results and Documentation Series, Danida Forest Seed Centre, Humlebaek, Denmark no.5: 1-26.

Rabiou H, Tougiani A, Dan Guimbo I, Issaharou-Matchi I, Weber JC, Dade H, Katkore B, Mousssa, B, Mahamane A. 2017. Dynamic plantations: intraspecific variability in growth of five varieties of Ziziphus mauritiana (Pomme du Sahel) and development trajectories in the Sahelian region of Niger. International Journal of Current Engineering Sciences 6: 128-135.

Rinaudo T. 2007. The development of farmer managed natural regeneration. LEISA 23, 32–34.

Sacande M, Ronne C, Sanon M, Joker D. 2018. Adansonia digitata L. Seed Leaflet no. 109. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry Centre. Addis Ababa, Ethiopia.

Samaké O, Kalinganire A, Koné B, Doumbia M, Dakouo JM, Weber JC, Mounkoro B, Ky- Dembele C, Uwamariya A. 2014. La Culture du Tamarnier : un manuel pour l'horticulteur sahélien. ICRAF Technical Manual No 23 Nairobi : World Agroforestry Centre.

Sanou H et Lamien N. 2011. Vitellaria paradoxa, karité. Conservation et utilisation durable des ressources génétiques des espèces ligneuses alimentaires prioritaires de l'Afrique subsaharienne. Bioversity International (Rome, Italie)

Sanou H, Kambou S, Dembele M, Yossi H, Sina S, Djingdia L, Teklehaimanot Z and Bouvet J-

M. 2003. Vegetative propagation of Vitellaria paradoxa by grafting. Agroforest Sys 60: 93–99.

Savadogo P, Ky-Dembele C, Carsan S. 2020. Réussir la plantation des arbres au Sahel. Manuel Technique. World Agroforestry (ICRAF/WCA/SAHEL).

Schmidt L, Joker D. 2018. Joker D. 2018. Balanites aegyptiaca (L.) Del. Seed Leaflet no. 21. Danida Forest Seed Centre. Provision of adequate tree seed portfolios (PATSPO). PATSPO – World Agroforestry. Addis Ababa, Ethiopia.

Sexton GJ. 2013. Khaya senegalensis (Meliaceae), genetic variation, life history and conservation. Thesis submitted for the degree of Doctor of Philosophy at the University of Queensland, Australia. 131p.

Sidibe M, Williams JT. 2002. Fruits for the Future – Baobab (Adansonia digitata L.). International Centre for Underutilised Crops, Southampton, UK, 96p.

Sina S. 2006. Reproduction et diversité génétique chez Parkia biglobosa (Jacq.) G. Don. PhD Thesis Wageningen University, Wageningen, Netherlands.

Sinare H, Gordon LJ. 2015. Ecosystem services from woody vegetation on agricultural lands in Sudano-Sahelian West Africa. Agric. Ecosyst. Environ. 200, 186–199. doi: 10.1016/j.agee.2014.11.009

Snauwaet E. 2009. Phenology and controlled cross-pollination of tamarind (Tamarindus indica L.) in Mali. Dissertation presented to obtain the degree and title of Master in Biosciences: Agronomy. Ghent University, Belgium.

Sokpon N, Ouinsavi C. 2004. Gestion des plantations de Khaya senegalensis au Bénin. Bois et Forêts des Tropiques, 279(279), 37–46. https://doi.org/10.19182/bft2004.279.a20247

Some LM, Gamene CS, Verwey H. 1990. A study of the causes of poor germination of Anogeissus leiocarpus seeds. In: Turnbull, J.W. 1990. Tropical tree seed research: proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld, Australia, 21-24 August 1989. ACIAR Proceedings No. 28. pp.

Soloviev P, Niang TD, Gaye A. 2004. Propagation by grafting Sclerocarya birrea (A. Rich.) Hochst. in Senegal. Fruits 59(4): 275-280.

Soumaré A, Diedhiou AG, Kane A. 2017. Les plantations d'Eucalyptus au Sahel : distribution, importance socio-économique et inquiétude écologique. International Journal of Biology and Chemistry Sciences 11(6), 3005–3017. https://www.ifgdg.org

Tassin J, Bellefontaine R, Roger E, Kull C. 2009. Evaluation des risques d'invasion par les essences forestières introduites à Madagascar. Bois et Forêts des Tropiques, 299(1), 27–36.

Tchoundjeu Z, Asaah E, Bayala J, Kalinganire A, Mng'omba. 2012. Vegetative propagation techniques. In: Dawson I, Harwood C, Jamnadass R, Beniest J (eds) Agroforestry tree domestication: a primer. The World Agroforestry Centre, Nairobi, Kenya. pp. 110-117.

Teklehaimanot Z. 2008. The role of indigenous fruit trees in sustainable drland agriculture in Eastern Africa. In: Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P and Kwesiga F (eds.). Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization. CABI International Publishing, Oxfordshire, pp.204-223.

Thibaut R. 2008. Etude des modes de régénération à faible coût de Prosopis africana et Detarium microcarpum en forêt classée de Dinderesso. Créteil : Université de Paris-Val-de-Marne, 71 p. Mémoire de Master 2 : Biologie. Bioressources en régions tropicales et méditerranéennes : Université de Paris-Val-de-Marne.

Tougiani A, Rabiou H, Dan-Guimbo I, Weber JC, Dade H, Katkore B, Moussa B, Mahamane A 2017. Morphological and phenological characterization for 5 improved varieties of Zizyphus mauritiana in Niger. International Journal of Development Research 7(10): 16224-16230.

Tougiani A, Guero C, Rinaudo T. 2009. Community mobilization for improved livelihoods through tree crop management in Niger. GeoJournal 74:377–389. doi: 10.1007/s10708-008- 9228-7.

UNDP. 2003. Human Development Report 2003. Millennium Development Goals: A Compact among Nations to End Human Poverty. Oxford University Press, London [available at http://hdr.undp.org/reports/global/2003/].

UNFCCC. 2015. Report of the Conference of the Parties on its twenty first session, held in Paris from 30 November to 13 December 2015. UNFCC/CP/2015/10/Add.1. Rio de Janeiro: UNFCCC.

Watson L, Dallwitz MJ. 1993. The genera of Leguminosae-Caesalpinioideae and Swartzieae: descriptions, identification and information retrieval. http://delta-intkey.com.

Weber JC, Sotelo-Montes C, Soumana I, Diallo BO, Abasse T, Larwanou M, Bationo AB. 2018. Genetic and geographic variation in growth of Balanites aegyptiaca in Niger: comparing results from provenance/progeny tests in the nursery and field. New Forests https://doi.org/10.1007/s11056-018-9686-9

Weber CJ, Montes CS, Kalinganire A, Abasse T, Larwanou M. 2015. Genetic variation and clines in growth and survival of Prosopis africana from Burkina Faso and Niger: comparing results and conclusions from a nursery test and a long-term field test in Niger. Euphytica 205: 809-821.

Weber JC, Larwanou M, Abasse TA, Kalinganire A. 2008. Growth and survival of Prosopis africana provenances tested in Niger and related to rainfall gradients in the West African Sahel. Forest Ecology and Management 256: 585-592.

Zida WA. 2020. Dynamique du couvert végétal forestier des agrosystèmes sahéliens du nord du Burkina Faso après les sécheresses des années 1970–1980: Implication des pratiques d'aménagement des terres. Université du Québec à Montréal, Canada