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Opportunities and challenges in the improvement of the shea (*Vitellaria paradoxa*) resource and its management

Report submitted to the Global Shea Alliance

Jean-Marc Boffa, PhD

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Jean-Marc Boffa is a system agroforester with a broad interest in farming systems, production ecology, tree domestication and landscape biodiversity conservation. He has many years of experience in Western, Central and Eastern Africa and the Mediterranean, including positions at Bioversity International (ex-IPGRI) in Rome, the World Agroforestry Centre in Uganda and Kenya, the University of Malta's Institute of Earth Sciences and the Centre de coopération Internationale en Recherche Agronomique pour le Développement in Cameroon. His current interests focus on strategic research planning in various aspects of smallholder agroforestry systems development. He currently works as a consultant and Associate Fellow of the World Agroforestry Centre. He received his PhD in Forestry and Natural Resources from Purdue University and 'Ingénieur' degree from the Institut Supérieur d'Agriculture in Lille, France.

Abbreviations and acronyms

AM	Arbuscular mychorrhizal
BA	6-benzyladenine
BAP	6-benzylaminopurine
CAADP	Comprehensive Africa Agriculture Development Programme
CBE	Cocoa Butter Equivalent
CFA	Communautés Financières d’Afrique
CIFOR	Center for International Forestry Research
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CNSF	Centre National de Semences Forestières (Burkina Faso)
CRIG	Cocoa Research Institute of Ghana
2,4-D	2,4-dichlorophenoxyacetic acid
Dbh	Diameter at breast height
DRC	Democratic Republic of Congo
EC	European Community
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division
FCN	Fonds compétitif national
FLO	Fairtrade Labelling Organizations
GHG	Greenhouse Gas
GSA	Global Shea Alliance
IBA	Indole 3-butyric acid
ICRAF	World Agroforestry Centre
ICT	Information and Communication Technology
INCO	Programme for International Scientific Cooperation (European Union)
INERA	Institut de l‘Environnement et Recherches Agricoles (Burkina Faso)

INNOVKAR	Innovative tools and techniques for sustainable use of the shea tree in Sudano-Sahelian zone
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
LLC	Limited Liability Company
NGO	Non-Governmental Organization
NAA	Napthaleneacetic acid
NPK	Nitrogen Phosphorus Potassium
R&D	Research and Development
UK	United Kingdom

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Executive Summary

1. Pressures

Shea populations have been under pressure from the following factors ranked in order of their assumed magnitude:

1. Extension of cultivation periods, decreasing length and frequency or disuse of fallow periods, which are required for the traditional regeneration of shea populations.
2. Large-scale land investment and agricultural development projects for high-intensity, mechanized food and biofuel crop production removing shea trees in fields.
3. Uncontrolled tree cutting for firewood and charcoal production.
4. Past droughts have shifted the species distribution southward.

2. Challenges and risks

The following challenges and risks need to be managed when realizing opportunities for improving the shea resource and its management:

- Recalcitrant seeds, long juvenile period and relative lack of successful studies on vegetative propagation.
- Relatively long nursery production procedures and fairly low success rate of propagation methods.
- Very low outreach to farmers with improved planting material to date.
- Lack of a planting culture for indigenous tree species and shea, including cultural taboos against planting shea.
- Farmers with secondary land rights have weaker access rights to shea trees growing on borrowed fields. Demographic and resource commoditization trends lead to increased competition between users, stricter individualization of access rights to shea trees and an increased frequency of conflicts.
- Because it can be interpreted as a long-term claim to land, planting of improved shea trees on borrowed land is often restricted. Thus, caution is needed in selecting participating communities, households and planting locations not to increase social differentiation and resource conflicts between individuals or groups.
- Organized shea cultivation may cause the intra-household distribution of rights to shea trees to shift resulting in greater control of benefits by men while women are currently the main beneficiaries of shea activities.
- Annual production of shea nuts can be under-collected due to constraints in women's labour availability relative to other activities.
- Common misperception that all harvesting of indigenous trees for firewood leads to woodland degradation, while sound management involves both culling and regeneration of trees.
- Lack of knowledge about origin, management and governance of firewood production for sustainable sourcing.
- Rainfall seasonality and frequency of extreme events will continue to increase with climate change. Shea parklands are better positioned to cope with extreme events than treeless areas, but unless flood resistance varieties are encouraged, shea could be more likely to be displaced where flooding occurs.

3. Strengths and opportunities

The report identifies a number of strengths and opportunities:

- Strong tradition of natural regeneration and tree protection and selection practices during fallow and cultivation cycles where fallowing is still practised.
- Potential for intensified shea propagation and planting based on a series of available seed and vegetative propagation techniques which should be improved including grafting, stem cutting and *in vitro* propagation.
- Large amounts of diversity in desirable characteristics of shea to be utilized in domestication of shea, (fruits, nuts, fat content –e.g. >62% and quality, under 10 year-long gestation period, tree productivity, etc.).
- Germplasm characterization databases and a few provenance trials based on a series of germplasm collections conducted throughout the shea range
- Untapped potential for clonal deployment based on existing superior tree collections
- Partially unexplored opportunities to improve shea management and cultivation. Techniques to be more systematically investigated include fertilisation, irrigation, mycorrhizal inoculation, intercropping with shade-adapted crops and legumes
- Information gaps about climate and soil determinants of shea phenology and production calling for more systematically controlled experiments.
- Undeveloped certification and traceability systems for supplying shea processors with sustainably managed firewood
- Increased temperatures with projected climate change should expand suitable areas for shea in the northern part of the range where it is currently marginal and rainfall is predicted to increase. While rainfall change is more uncertain in the southern part, shea distribution should also expand southwards with increased temperatures.
- Because trees reduce temperatures and improve soil conditions for intercrops, shea agroforestry parklands provide a positive climate change adaptation measure in agriculture.

4. Recommendations

In the design of research programs for intensifying shea production the following basic principles are suggested:

1. Keep in mind that shea parklands are managed landscapes where shea and other economic species have been favoured by local farming communities through cyclical selection and management for generations for human use.
2. Strategies for improvement should thus build on and improve existing management practices rather than attempt to reinvent a brand new domesticated production system.
3. Development activities that enhance income and other benefits derived from the trees will directly encourage more active parkland management, maintenance and enrichment.
4. Improved management of the shea resource should not be circumscribed to the planting of improved shea stands in the proximity of farmers' compounds, but needs to be conceived as an integrated landscape-wide approach combining a series of relevant parkland regeneration and tree improvement and management interventions in fields, fallows, bush lands making up village landscapes.

5. Use it or lose it. Resource (shea and other compatible multi-purpose species – baobab, marula, néré, etc.) harvesting and uses (e.g. firewood, fruit, medicine, fodder, construction, etc.) in parklands are the central motivation for their maintenance; discouraging such uses would inevitably lead to a notable loss of diversity in shea production systems.

6. Carefully evaluate and manage the social and land tenure impacts of organized shea cultivation including the privatization of shea tenure, women's usufruct rights, and their participation in the shea value chain.

The following specific research and development recommendations are also proposed:

Parkland management	• Analyse trends and spatially quantify fallowing practices over time through longitudinal village-level spatial analysis and field surveys of farmer practice
Parkland regeneration	• Farmer sensitization and education campaigns about land use change (fallow decline) and need to intensify tree regeneration and management • Mainstream and improve the effectiveness of various propagation and tree management techniques in farmers' fields including transfer of wildlings, grafting on wildlings, seeding under existing shrubs, direct seeding, planting of nursery-grafted material, farmer-managed or assisted natural regeneration, air-layering, etc • Mobilize farmer and local leader participation for identifying and strengthening a set of model parklands to demonstrate the value and benefits of intensified shea management involving the upscaling of parkland regeneration and tree propagation techniques
Shade-tolerant crops under shea trees	• Assess productivity of C3 crops under shea and monitor performance over several seasons and under varying agroecological conditions
Factors influencing fruit production	• Better understand the effect of climate and soil moisture on shea phenology and production • Study of pollinators and pollination efficiency • Experiment with amounts and timing of irrigation of mature shea stands and assess effect on fruit yields • Assess impact of NPK fertilization, girdling, pruning for parasite removal and crown pruning on fruit productivity

Propagation techniques

Nursery production	• Develop fertilizer recommendations for nursery seedling production, hardening and field establishment • Survey local successful nurseries and develop an extension manual on best practices in shea nursery production and field establishment • Perception survey with purchasers of improved/grafted shea seedlings
Stem cuttings	• Improve the development of practices that reduce fungal infection and increase rooting success
Grafting	• Improve and mainstream implementation modalities of grafting techniques to attain higher success rates in the field
***In vitro* propagation**	• Ensure higher success rates in rooting shea explants in vitro and better understand the influence of cytokinin/auxin ratios and genotype on response to in vitro regeneration

Diversity analysis and domestication

Diversity analysis	• Assess post-harvest changes in seed chemistry as a basis for increasing accuracy of fat diversity studies • Assess environment and genetic basis of variation patterns in fat composition
Germplasm collection and evaluation	• Organize region-wide collection and assessment of superior shea germplasm building on past collection data • Establish replicated multilocational provenance trials for comparing attributes and testing local adaptation of provenances, and studying of genetic x environment interactions
Clonal propagation	• Multiply and disseminate elite *Vitellaria* germplasm (adapted landraces, regional ecotypes) on a large-scale using grafting techniques and both station-based and farmer or village nurseries/mother gardens
Genetic resource conservation	• Promote the development of national and regional plans for shea genetic resource conservation and coordination of shea conservation efforts between countries
Indigenous tree planting	• Conduct research on the removal of key constraints to indigenous tree planting. What are the key impediments (germplasm availability, costs and benefits, tenure, cultural taboos, silvicultural knowledge, etc.) and in which contexts? • Review and generate lessons from shea plantation experiences • Awareness raising and advocacy strategies to encourage indigenous tree planting, including school education programs, and demonstrations of planted shea stands with high public visibility on lands having no usufruct conflict

Constraints that women encounter in shea activities

Addressing under-collection of shea nuts by women	• Assess women's opportunity costs of investing resources in shea-related activities in comparison with competing activities • Document shea nut collection strategies across fields, fallows and bush land in different conditions of land and tree tenure • Participatory technical improvements in efficiency and safety of shea nut collection, reduction of fuelwood and water use in post-harvest processing, and methods for drying boiled nuts
Resource access by women	• Monitor trends regarding the privatization of shea tenure, women's usufruct rights, and encourage women's involvement in their participation in the shea value chain

Resource use in shea processing

Reduce fuelwood use and carbon emissions in shea processing	• Document women's strategies for fuelwood collection in village landscapes • Understand factors (resource condition and governance, technology, household assets, group membership, knowledge, etc.) which influence fuelwood consumption vis-à-vis parkland fuelwood productivity and identify opportunities for improved resource management and use • Promote the commercialization and wider availability of shea (husks and cakes) and other agricultural residues for use by women processors • Assess women's functional requirements in shea processing; review and adapt cookstove designs with a focus on local acceptability
Encourage renewable energy production and use in parklands for the shea processing sector	• Identify sustainably managed firewood supplies by surveying and documenting woodland management and governance practices by local actors • Develop and verify these sources through traceable and certifiable systems so that sustainable biofuel can be provided at premium prices for targeted shea butter production systems, e.g. organic and fairly-traded

Impact of climate change on shea distribution	• Monitor impact of climate and climate-dependent pests and diseases on shea population trends (tree regeneration and health) in marginal northern and southern areas of the shea range

Keywords: agroforestry parkland, regeneration, tree planting, domestication, access rights, women

Figure 1. Dry-season shea parkland view (source: Antoine Kalinganire)

A. Introduction

Commonly known as the shea tree (karité in French), *Vitellaria paradoxa* C.F. Gaertn., was cited three decades ago as the second most important oil crop in Africa after oil palm by Poulsen (1981, cited in Hall et al., 1996) and is probably the most economically and culturally important tree species in the Sudano-Sahelian region of Africa where oil palm does not grow. Across the distribution area, the estimated actual number of productive trees and the estimated potential number of shea trees ranges from several hundred million (Lovett, 2004) to a couple of billion, respectively (Naughton et al., 2014), making it one of the largest tree population size of an economic tree species in the region. The dried kernel of the fruit is used to produce oil or fat (shea butter) for local consumption and is commercially sold as an ingredient in cosmetic, pharmaceutical and edible products. Shea was reported as a traded commodity by the Arab traveller, Ibn Battuta as early as the 14th century; the magnitude of its distribution and local importance caught the attention of early explorers such as Mungo Park in 1798 (Park, 2000) and has been a subject of research since colonial times (Chevalier, 1948; Ruyssen, 1957). Shea is estimated to be the primary edible oil for more than 80 million rural people (Naughton, 2014).

There is no central body registering shea production and trade. Cross-national transfers of production in West Africa occur without indications of source origin; the identity of exports may not be listed correctly as nuts, butter, stearin or other vegetable oil and the publication of import statistics of shea is not compulsory in European competition laws. Thus, published production statistics can be imprecise. As an indication of magnitude, the European "Improved management of agroforestry parklands in Sub-Saharan Africa" INCO research project estimated that total production of shea nuts in the whole of Africa in 2000 was 650,000 tons (Becker and Statz, 2003). In turn, Lovett (pers. comm. in Allal et al., 2013) estimated that an average of 600,000 tons of nuts is collected annually in West Africa.

Its natural range extends across 21 countries[1] from the eastern part of Senegal and Gambia to the high plateau of East Africa into south-eastern Uganda forming an almost unbroken belt, 6,000 km long and averaging 500 km wide (Hatskevich et al., 2011; Allal et al., 2011). This tree is virtually all self-sown but systematically farmer-selected in agroforestry parkland systems combining scattered trees and annual crops (Pullan, 1974; Boffa, 1999) (Figure 1). Farmed parklands, of which shea is a predominant species and proportion of the standing biomass, sustain local agricultural systems by conserving the natural resource base and enhancing their resilience to the harsh and variable climate. They also contain substantial carbon stores with high potential for future carbon sequestration toward climate change mitigation (Takimoto et al., 2009; Luedeling and Neufeldt, 2012).

However, increasing demographic pressure on land has resulted in an increase of cultivation periods and reduction, and in some places, the disuse of fallow cycles. Shea regeneration traditionally takes place in fallows (Raebild et al., 2012); therefore the modern evolution into mechanized farming practices has not favoured the sustainability of shea populations. Shea tree densities have been declining; trees have been ageing and regeneration is low (Gijsbers at al., 1994; Boffa, 1999). Farmers collecting shea nuts need to travel longer distances, increasing the labour required for nut collection. Also, the relatively recent emphasis on large-scale land investment and agricultural development projects aimed at intensifying maize, cotton and biofuel production with mechanized (tractor) farming are a threat to the retention of shea trees in farmers' fields (Poudyal et al., 2011). Large-scale land investments for biofuel and food crops in West Africa as a whole amount to over 4.4 million ha (Land Matrix, 2014). While the total cumulative value for local livelihoods and environmental conservation is considerable, the

1 Benin, Burkina Faso, Cameroon, Central African Republic, Côte d'Ivoire, DRC, Ethiopia, Gambia, Ghana, Guinea-Bissau, Guinea-Conakry, Mali, Niger, Nigeria, Sierra Leone, Senegal, South Sudan, Sudan, Chad, Togo and Uganda

upstream per-unit value of shea nuts in the trade of bulked shea nuts for industrial extraction is low and returns to individual collectors and local economies small (Louppe, 1994). In some places lack of transport and market infrastructure result in underutilization of the shea resource (Masters, 2008). Elsewhere in areas of high energy demand competing uses of shea in parklands or uncultivated woodlands may be favoured such as tree cutting for firewood and charcoal making leading to the degradation of shea stands. The above raises concerns for the sustainability of the resource and possibilities of future production gaps. However, the impacts and relative significance of each of these factors affecting the maintenance of shea populations over time are not fully understood and need to be methodically documented.

Over past years, shea production has significantly increased (Rousseau et al., 2015) and overall demand is projected to continue growing (LMC, 2014; Simmons, 2014). The number of development projects supporting various aspects of the shea value chain has flourished in recent decades and the diversity of actors has expanded. The ongoing professionalization of the value chain calls for higher resource supply consistency and quality. The development of the shea sector and potential benefits to women shea producers requires a vigorous, productive and sustainable shea tree resource base (Pouliot and Elias, 2013). At this juncture a strengthened focus on the improvement of this resource base and its management seems justified to address both the threats and rising demand for the resource.

Shea is not traditionally planted and the vast expanses of existing shea parklands in the 21 countries of its range result from self-sown propagation and systematic management (protection, selection and dispersal as opposed to planting) by local agricultural communities through successive fallow and cultivation cycles. Women have central roles in shea nut collection, processing, local knowledge management and they control revenues of shea-related activities. Therefore, *Vitellaria* is an important women's crop. However, their rights of access and management are not straight forward where patrilineal societies are dominant. They are mediated by male heads of households in arrangements that intricately depend on land tenure types, economic value of products collected and community contexts. The desirable paradigm shift to a more deliberate and active management and improvement of shea populations needs to be considered in the context of these unique features of the shea tree resource.

This study was driven by the need to:

- better understand the overall management characteristics of the shea tree resource,
- identify opportunities, risks, and knowledge gaps toward the improvement of the species and its management,
- provide recommendations on strategic elements, research and development needs and activities to be considered by shea sector participants.

B. Methodology

This document was developed based on the author's field experience, a review of published literature on shea and interviews with shea sector actors and researchers listed in the Acknowledgments page.

C. Some basic facts

1. Current production and market shares of shea

As mentioned above, only variable estimates are available for shea production. From national data of uncertain reliability, FAOSTAT reports an annual average production of 750,000 T of shea nuts between 2005 and 2013 for all producing countries combined in Africa. Lovett (2004) indicates that, of the quantities of shea nuts collected annually, 55% to 75% are consumed domestically while the rest, 25% to 45% are exported depending on sources. More recently, he estimated that exports amount to 200,000 (33%)–350,000 (58%) of the 600,000 SETs (Shea nut Equivalent Tons, inclusive of dry kernel, mechanically-extracted or hand-crafted butter and fractionated stearin) annually produced in Africa (pers. comm. in Allal et al., 2013). Yet figures appear to vary even more widely and Sidibe et al. (2012) estimate that in Mali domestic consumption and local trade amounts to 90% of total production. Differences between sources may relate to the share of nuts that are processed into butter and consumed at home without entering local markets. Thus there is a need to assess domestic shea consumption. In the shea export market, approximately 90% of the volume is for confectionary applications and 10% for cosmetic uses (Rousseau et al., 2015).

2. Main uses and applications

Local

- The fruit pulp is an important local nutritional resource, widely eaten by adults and children, and provides a rich source of ascorbic acid, iron, calcium, and vitamins A and B (Hall et al., 1996) (Figure 2).

Figure 2. Shea fruits (source: Global Shea Alliance)

- The vitamin and mineral-rich vegetable butter extracted from the nut provides a preferred (and sometimes the only locally available) cooking oil of most households in the region. It enhances the taste, texture and digestibility of the local dishes.
- Shea butter is also used locally as a skin and hair moisturizer, in soap making, as a waterproofing wax and illuminant (Figure 3). It is applied to African percussion instruments (djembe shells, calabash gourds) to increase the durability of wood and leather tuning straps.
- Its medicinal properties are known to relieve rheumatic and joint pains and to quicken healing times and prevent infection of open wounds. It is also widely used to treat skin problems such as dryness, sunburn, burns, ulcers and dermatitis (Marchand, 1988 cited in Moore, 2008).
- Secondary shea products include honey and edible caterpillars, while shea processing yields abundant quantities of shea husks used as compost and shea cakes provide a source of fuel.
- The wood is used for charcoal, construction, for furniture and as pounding mortars (Dalziel, 1937; Abbiw, 1990). The bark is used for traditional medicines and the latex is used for making glue. Shea trees provided fodder for 70% of surveyed households in Nyankpala, northern Ghana (Poudyal, 2011).

Figure 3. Processed shea products from COFTRAKOL women's group in Bangangte, Cameroon (source: Ann Degrande)

International

- Shea's largest international outlet is in chocolate confectionary where shea stearin is separated for use as an ingredient in cocoa butter equivalents (CBE) or improvers, while shea olein is used as a base for margarines and as a component of animal feeds.
- Shea butter (including fractions and derivatives) is marketed internationally as an ingredient for manufacturing cosmetics (moisturising creams, paper wipes, sun lotions and soaps).
- In the pharmaceutical sector shea has been used as a base for medicinal ointments, as anti-inflammatory treatment for arthritis and a topical treatment for eczema and other skin conditions including herpes lesions, as well as in nutraceuticals for lowering cholesterol.

3. Shea's local socio-economic and cultural importance

Collection of shea nuts is a universal household activity in shea's distribution range while their marketing is done by a smaller yet considerable proportion of rural households. In two large samples in south-western and southern Burkina Faso, percentages of surveyed households involved in the collection and commercialization of shea nuts were 94% and 59% respectively, while 39% of women processed butter at home (Pouliot, 2012).

Shea products are particularly valuable to the poorest households, which derived 12% of their total household income (total value of produced outputs minus purchased inputs) from shea fruits and nuts in Pouliot's study (2012), compared to only 4% for better-off households.

The seasonality of shea availability is also critical for farming households' nutrition. The fruit ripens and falls from the tree during the annual 'hungry season', when cereal stocks in granaries are lowest and labour requirements for clearing land and planting crops with the coming of the rains are highest. Shea nut production and income fill an annual production gap, being at the highest between July and October, while harvesting of agricultural products takes place between October and December (Pouliot, 2012). Average household cash income from shea products represented about 17% of the annual cash income from agricultural crops (Pouliot, 2012).

4. A women's crop resulting in gendered landscapes

The shea resource is the domain of women because within the household they are traditionally responsible for gathering of non-agricultural products (e.g. wild fruits). Specifically, the collection and processing of shea nuts is most often done exclusively by women and girls (Figure 4). Very significantly, and unlike most cash crops, women control the revenues from the sale of shea butter – which they use to take care of the cash needs of their households and families.

Figure 4. Women taking shea harvests home to process (source: Peter Lovett)

The rich knowledge system surrounding the processing of shea butter which women acquire at a young age has been passed on for generations from mother to daughter (Elias and Carney, 2007). Shea butter production is a woman's identity marker and is a way rural women cement their social ties. High butter quality is a source of recognition and good reputation for them.

Shea has particular socio-cultural values to women. The butter is used by women during pregnancy and on newborn babies, and is offered as a gift from women to women to celebrate marriage, births or for dowries. It is also used for lamps used on graves and in funeral processions. Women's participation in decision-making related to shea may also be reflected in parkland characteristics. In Thiougou, sourthern Burkina Faso, shea density on personal fields controlled by women (27 trees /ha) was higher than on the personal fields of male household heads (20 trees/ha) (Boffa, 1995).

D. Challenges and opportunities for shea resource improvement

1. The selective effect of human management

Shea is not a wild, but a semi-domesticated crop resulting from long-term anthropogenic selection by indigenous farming communities for specific desirable attributes (vigour, fruit productivity and characteristics, combining ability with crops, etc.) through cultivation and fallow cycles (Boffa, 1999; Lovett and Haq, 2000a; Maranz and Wiesman, 2003). The decision to keep or to cut naturally regenerating saplings as a component of an agroforestry system, means that semi-domestication may be occurring through the process Harlan (1992) describes as 'automatic' or 'unconscious' selection.

A large body of evidence shows that shea populations are not free of human management (Pullan, 1974). According to Ruyssen (1957) citing Aubréville, the early botany expert of Africa, there are no "primary" Vitellaria populations in West Africa and shea is not found in old dense dry natural forest remnants. Thus current shea populations probably derive from source populations that no longer exists and are intimately linked to man's presence and human activities of tree protection, selection and dispersal.

Figure 5. A recently cleared fallow in south-western Burkina Faso showing results of tree selection, proportional increase of shea trees, reduction of tree density and species diversity as the cultivation cycle begins (source: Peter Lovett). Cut trees are not always killed, and, if left, will grow back in a coppiced manner during fallow periods.

Studies comparing uncultivated and farmed parkland areas provide insights on the nature and extent of farmer management responsible for the transformation of savannah vegetation into shea parklands. While clearing and readying a piece of land (whether in natural forest or fallow) for cultivation (Figure 5), farmers eliminate most trees (9 out of 10 trees in Thiougou, Southern Burkina Faso for instance) and protect *Vitellaria* as a key economic species (among several others to a lesser extent), thereby increasing its relative abundance on agricultural land with respect to other woody species. The clearing process also removes one third of the woody species' pool found in uncultivated conditions. In southern Burkina Faso, the relative occurrence of shea trees in cultivated fields was five times greater than in uncultivated savannah. In northern Ghana and Burkina Faso, shea accounts for more than 80% of the woody plants on farmed land (Boffa, 1999; Lovett and Haq, 2000a), while it represents only 16% of those in uncultivated bush (Boffa, 1995). This farmer-driven increase in the abundance of shea trees relative to other species takes place at the scale of individual farms; but this continuous and cyclical dynamic process over generations (millennia) of land-use is multiplied by the millions of farmers over its distribution area for whom shea is a primary fat source, boosting its population size to one of the largest among economic tree species in the region.

In Burkina Faso, shea trees were about twice as large in diameter in cultivated fields as in uncultivated conditions, on average (Boffa, 1995) and a similar trend is reported in studies in Benin (Djossa et al., 2008), Mali (Kelly et al., 2004), Cameroon (Mapongmetsem et al., 2011), and Uganda (Byakagaba et al., 2011). Average fruit yield per tree, the proportion of fruiting trees in the population as well as fruit size and weight were also higher in agroforestry parklands than in neighbouring woodlands (Lamien et al., 2004). Such aspects of superior performance in cultivated areas result from the combination of locally superior tree selection by farmers, soil management practices, tree density reduction (of other species and some unwanted shea trees) lowering plant competition for resources as well as protection against fire and grazing control.

Fallows represent the management phase alternating with cultivation cycles when all woody vegetation is allowed to regenerate while the land is rested. Tree density, especially the class of small, young individuals increases during the fallow period, as does species diversity. The fallowing process also restores soil fertility. Competition between woody plants is more acute than in farmed parkland conditions where individual trees are more distant from each other. Also because of the more abundant grassy and bushy layer, fire is a more common occurrence. Over time, the appearance of a previously cultivated field under fallow gives way to the look of uncultivated bushland or woodland. Therefore areas that are commonly referred to as 'natural woodlands' or bush lands are typically lands in a state of fallow of variable length. The presence of scattered large shea trees and other economic species which date back to former cultivation cycles invariably shows that they have been farmed before and will be farmed again (Boffa, 1999; Maranz and Wiesmann, 2003; Lovett, 2014). It is important to emphasize that these seemingly 'natural' areas, which make up shea nut production systems along with farmed parklands, are not 'wild' or 'natural' woodlands. Instead they have been and continue to be subject to human management of a different nature according to land use patterns at any given time.

Anthropogenic management of shea trees in farmed parklands extends beyond species protection to the selection of preferred individual trees. Trees with robust growth patterns and desirable fruit and nut traits are deliberately selected and protected while undesirable individuals are culled for firewood or construction. Farmer selection occurs at clearing time as well as in later years. A third of farmers interviewed in Southern Burkina Faso declared carrying out shea tree selection when clearing vegetation based on visual tree characteristics, while two thirds claimed that they evaluate production potential of trees over a period of 2 to 6 years and remove additional shea trees accordingly (Boffa, 1995). Preferred traits reported by farmers in Northern Ghana included good health, low competitive effects on crop yield, large sweet fruit, high yield, fast growth and resistance to mistletoe (Lovett and Haq, 2000a).

Outcomes of such anthropogenic selection and management are evident in several characteristics of shea populations highlighted by Maranz and Wiesman (2003). If local fruit collectors were only harvesting from ‘wild’ trees, one would expect quantitative fruit traits to vary randomly and independently or to follow an environmental gradient. This is not the case. Removing inferior individuals over centuries has concentrated desirable traits in shea populations, as illustrated on the Mossi/Central Plateau in Burkina Faso, an area where shea is a central component of local livelihoods. There, shea populations were higher in locally valued characteristics including large fruits, sweet pulp, and high kernel fat content compared to other locations in a germplasm collection including origins in Mali and Burkina Faso (Maranz and Wiesman, 2003). Also, the variation in fruit sweetness between three climatic zones within this area of collection was reduced compared to other regions, highlighting the homogenizing role of farmer selection.

Historical records indicate that man’s influence in establishing and maintaining woody species in agriculture dates back to several millennia ago. For instance, Ballouche and Neumann (1995) provided palynological evidence that closed grassland vegetation changed to a shrubland typical of agropastoral activities circa 3000 years ago in northern Burkina Faso when human populations settled in the region. Evidence of *Vitellaria* seed testae and charcoal together with abundant pearl millet remains was also found in an excavated village dating from 1000 years ago indicating the development of a parkland agroforestry system from a pre-existing grassland with little woody vegetation (Neumann et al., 1998). A number of other woody fruit plants including baobab (*Adansonia digitata*), persimmon (*Diospyros mespiliformis*), marula (*Sclerocarya birrea*) and jujube (*Ziziphus spp*.) also appear in the paleobotanical record after human settlement of the area.

Evidence of more recent deliberate human dispersal of shea has also been produced. Nowadays shea occurs in several clusters further west of the limit of its distribution area as documented by explorer Mungo Park in Senegal in the late 1790s (Maranz and Wiesman, 2003). Interviews with local inhabitants reveal that these stands result from the establishment of shea trees from seed one or two generations ago by immigrants from Mali and their subsequent natural regeneration. A similar process has likely taken place in the Fouta Djalon highlands of Guinea where shea was said to be extremely rare in colonial times (Ruyssen, 1957), while it is now abundant on the Mali and Labé plateaus in this region (Maranz and Wiesman, 2003). These authors go on to explain that chain length and percentage of unsaturated fatty acids in oil seeds increase with cooler temperatures. Such high unsaturated fatty acid proportions were found in high elevation Ugandan and West Cameroonian *Vitellaria* populations, while the Fouta Djalon samples had unsaturation traits similar to those found in lowland shea populations. The recent anthropogenic transfer of shea from lowland sources would explain why this adaptation feature to high elevation and cool climate was not manifest in the Fouta Djalon populations.

These semi-domestication processes are important to recognize, in terms of their integrated character in local farming systems, their scale in both space and time, as well as their impact on the ecology, sustainability and production potential of this ancient crop. Selection and management activities have been ongoing for centuries, have profoundly transformed landscapes increasing shea’s abundance, gene flow between populations and productivity. This transformation has been effected by the decisions and management practices of millions of farmers across its geographic range. It is therefore recommended that modern resource improvement strategies seek to build upon existing parkland and tree management practices, indigenous know-how and local participation surrounding this man-managed crop. An effective shea domestication approach ought to implement steps to improve this traditional farming system and make it more sustainable and adapted to the realities and needs of the 21st century, rather than attempt to reinvent a brand new domesticated production system. These efforts should be guided by the principle that the multiple benefits (income, fuelwood, building poles, soil quality, etc.) a shea collector (and her family or community) derives (vis-à-vis income from other livelihood options/ enterprises/crops) is one of the critical drivers of how future shea landscapes will be managed.

2. Diversity of a semi-domesticated resource

Variation and factors affecting productivity

Inter-annual variation: Shea production is characterized by variable cycles of good, average and poor harvests affecting export volumes and perception of sustainability of the sector. In young shea parklands of Thiougou, Southern Burkina Faso, the 3-year average nut yield of 53 trees was 2.4kg (Boffa et al., 1996). However, average yields were almost five times higher in years 2 and 3 than in year 1, showing patterns of variable annual bearing. Alternate bearing patterns originate from carbohydrate deficit in plant organs resulting from high production during one season which generally leads to low production during the next season (Monselise and Goldschmidt, 1982). Alternating cycles can be regularly maintained over several years or be interfered with by climatic or pathological factors.

Intra-population variation: There was also a five-fold difference between the best producing trees and the population average, indicating the potential for selection and improvement (Figure 6). In the sample population, 42% of the trees were consistently very low producers and their contribution represented less than 10% of total production. High producers in two or three years represented 15% and 9% of the whole sample, but 35% and 20% of total production (Table 1). Productivity thus appears to depend both on the genetic makeup of the tree as well as external factors.

Tree age: Shea trees are slow-growing and long-lived. Nut production increases with tree age. It becomes significant between 20 and 30 years of age, increases until age 100 to 200 and would slowly decline afterwards. It has been estimated that shea trees may then live up to 200 or 300 years (Delolme, 1947; Ruyssen, 1957), yet no dendrochronological or carbon-dating studies have yet been reported for shea. However, no correlation was found in the Southern Burkina Faso study between fruit yield and tree diameter over the relatively limited range of 10-44 cm dbh (Boffa et al., 1996). Similarly Kelly et al. (2007) did not find any difference in flowering parameters according to tree size in their study. Yield variations linked to tree age are thus expected over the lifetime of trees but may be small over limited age intervals.

Figure 6. Shea tree displaying abundant fruit production (source: Eliot Masters)

Table 1. Interannual variation of shea nut yields from Vitellaria paradoxa trees in Southern Burkina Faso during 1993-1995 (Boffa et al., 1996)

3-year production	Number of trees Years when nut yield>annual average				Total
	0/3	1/3	2/3	3/3	
0-3.5kg	17	-	-	-	17
3.5-7.319*kg	5	11	-	-	16
7.32-15kg	-	7	3	2	12
>15kg	-	-	5	3	8
Total	**22**	**18**	**8**	**5**	**53**
Total	**42%**	**34%**	**15%**	**9%**	**100%**

***7.319kg is the 3-year production mean in the sample**

Climatic factors: Several authors have proposed general hypotheses relating climate to fruit productivity, but these have not been investigated systematically. The contributions of climate (rainfall, temperature) and soil factors to variations in shea phenology and production need to be further quantified and disaggregated, and optimum conditions assessed.

Temperature: Higher minimum temperatures during flowering (November through February) results in higher nut yields according to Desmarest (1958). Because average minimum temperatures decrease regularly in the Sahel from November to January as the relatively cool dry season progresses, an early start of flowering would also result in higher nut production. However, in Uganda fruiting frequency (not fruiting quantity) in *ssp. nilotica* was weakly positively correlated with mean daily temperature while it was strongly negatively correlated with both relative humidity and wind speed (Okullo et al., 2004). Similarly bush fires during flowering especially later in the dry season and the harmattan - that blows south from the Sahara across the Sahel during the cool, dry season - can adversely affect the timing and quantity of flowers produced and hence have a negative effect on production (Ruyssen, 1957). In Uganda, flowering was concentrated late in the dry season after the occurrence of most fires, so that disruption of the reproductive process and damage of reproductive organs by fire was minimized (Okullo et al., 2004).

Soil moisture: No clear pattern regarding the effect of rainfall on shea productivity has yet been identified. Delolme (1947) hypothesized that sufficient soil water reserve or the absence of drought at the time of flowering and fruit set would allow higher fruit yields. Using the example of two contrasted years, this author mentioned that an early end of the rainy season and low rainfall in the last weeks followed by a drought might be the reason behind low fruit set during the following fruiting season. However, using rainfall and nut production data of a shea population over eleven years, Ruyssen (1957) showed that there was no systematic correlation between amounts of rain fallen in one year and fruit yield the next year. The relationship between rainfall and subsoil water content that trees can draw from over the dry season, depth of water table and how this varies by soil profile type and latitude would also need to be elucidated.

Flowering ability and probability of abundant flowering over two years were higher in a north Guinean site in Mali characterized by higher rainfall, lower mean annual temperature and higher relative humidity than a compared south Sudanian parkland site (Kelly et al., 2007). The flowering period started earlier and was shorter in the more favorable climatic conditions. However, the Guinean site also appeared to have more fertile soils; yet soil conditions were not investigated. Thus, the respective impact of climatic conditions (temperature, air and soil moisture) and soil fertility factors and their interactions on shea phenology and production remain an open field of investigation for improved shea management.

Irrigation experiments of shea stands in the drier part of the range and contrasted wetter sites, for instance with water collected through locally appropriate water harvesting techniques, could help define appropriate amounts and timing of water supply for maximizing flowering, fruit set and fruit production.

Soil type and nutrient status: Shea is incompatible with some soil types. It avoids even temporarily flooded areas and does not occur on highly sandy or clayish soils. The species is well adapted to poor shallow soils and land suitable for rainfed crops (Ruyssen, 1957; Picasso, 1984). Soil fertility influences growth and production in that shea trees are more vigorous on deep alluvial soils than on lateritic gravelly soils and they may yield more on fertile soils in low production years. However, authors differ in their interpretation of the influence of soil fertility on the large differences in productivity that one finds in stands of mature shea trees. Delolme (1947) identified three groups of neighbouring shea trees of similar diameters and production and reported yield differences between them that were ranked similarly over two years. He attributed yield differences in these stands to soil types through an appreciation of grass height and vigour under the trees. However, the latter assessment was visual and unquantified and the undisclosed sampling metholodogy does not rule out other determining factors. Conversely, Desmarest (1958) conducted a series of auger-based soil texture assessments at various soil depths under trees of contrasted yields and found similar soil profiles. He concluded that soil type was not responsible for the large observed tree-to-tree productivity variations. The same conclusion – that soil type has little influence on shea production – was reached by Picasso (1984).

Weed control by hoeing, intercropping beans and manure application had positive effects on fruit yields in Ghana (Hall et al., 1996). N and P fertilization in nursery conducted by Dianda et al. (2009) stimulated the growth of 6-month old shea seedlings but response depended on the ratios between both nutrients. N limitations appeared to be the main constraint to biomass accumulation. When investigating the N requirements for optimal growth of shea seedlings, N dosage much lower than 12 $mg.kg^{-1}$ should be used under conditions of P shortage. External N inputs relative to P supply and possibly soil K concentration was recommended for successfully using mineral fertilizers in shea nursery production. This experiment also showed that shea is a susceptible host species to the arbuscular mycorrhizal (AM) fungus *Glomus intraradices*, yet no benefits of AM fungi inoculation to seedling growth were evident, probably because no P stress occurred.

Pollination: Shea is an outcrossing species (Yidana, 1994). Bees play an important role in pollination (Sallé et al., 1991) and shea pollen occurs in honey samples (Schweitzer et al., 2014). However, relatively little research has been done on this aspect.

Girdling: Lamien et al. (2006a) demonstrated that shea responds to girdling, a technique used to control fruit yield irregularity by causing carbohydrate and hormonal accumulation in stems and leaves located above the incision point. The technique resulted in a 100% increase in fruit production. No significant difference between girdling dates (August when fruit fall ends and late November when leaf fall starts) was observed. The technique can be recommended with the specification that incisions are made in ways to ensure rapid wound closure. Nevertheless assessment of girdling's long term effects on trees is desirable.

Vegetation management: Flowering attributes in shea trees located in fields were consistently more favourable than in fallow or forest locations (Kelly et al., 2007). Thus farming activities which result in the structuring of agroforestry parklands enhance flowering of shea. Likewise average fruit yields measured in a single year were higher in agroforestry parklands (4.3kg/tree) than in neighbouring natural woodlands (1.6kg/tree) and the proportion of trees with zero fruit production was 16% in agroforestry parklands and 48% in natural woodlands (Lamien et al., 2004). Average tree diameter as well as fruit size and weight were also larger in parklands than those in uncultivated plots. These more favourable conditions probably reflects the combined positive factors of farmer selection of trees, cultivation practices on soil nutrient status, reduced tree competition, larger tree size, as well as control of grazing and bush fires.

Parasitism: Another potential factor affecting tree productivity is shea's vulnerability to infestation with hemiparasitic plants (Loranthaceae), including three species of mistletoe parasites *Agelanthus dodoneifolius*, *Tapinanthus globiferus* and *T. ophiodes*. Infestation rates are reported to be high in West African parklands, 95% in Burkina Faso (Boussim et al., 1993) and 81% in Nigeria (Odebiyi et al., 2004). Shea's nutritional deficit caused by the parasites is said to lead to discontinued growth, decline and death of the distal part of infested branches. As parasites can grow rapidly and insert themselves in multiple locations deflecting water supplies away from the host, infestation can cause generalized tree weakening, permanent defoliation, drying out of affected tree parts, lowered flowering and fruiting and tree death. The latter is a common sight in the Northern part of shea's range in Burkina Faso where trees are also subject to droughts and harsh winds (Boussim et al., 1993; Boussim et al., 2004).

The frequency of *Tapinanthus* infestation is considerably higher in shea trees in cultivated parklands (80%) than in protected natural woodland areas (27%) and the parasite load was higher in parkland trees (Houehanou et al., 2011). Larger trees also tend to be more heavily infested. These differences in infestation rates between parklands and natural woodlands are probably due to the larger average size of shea trees in parkland conditions which provide greater infestation potential and higher production of parasite seed, as well as more intense dispersion by birds in the more open parkland environment. However, presence/absence of parasites did not result in differences in flowering or fruiting of shea branches (Lamien et al., 2006b) and the level of parasite infestation (1-3 vs. 10-14 parasite branches) had no significant impact on fruit production in either parkland or natural woodland conditions (Houehanou et al., 2013). These specific results tend to alleviate concern for the potentially negative impact of Loranthaceae parasites, as a single agent, on shea fruit productivity. Yet these parasites remain a strong concern for the sustainability of northern shea tree populations which are subject to additional climatic stresses such as droughts.

Diseases and pests: Shea is a hardy species and its vulnerability to fungal diseases is low. Attacks by *Fusicladium butyrospermi* Griff. and Maubl. and *Pestalozzia heterospora* Griff. and Maubl. are limited to dark brown or grey spots on shea leaves (Sallé et al., 1991). However, shea also has a number of insect pests. Sallé et al. (1991) documented a diversity of herbivorous insect pests attacking various parts of the tree in West Africa. In the Southwest and Northwest of Nigeria where shea is found, Odebiyi et al. (2004) found 33 insect pest species from 17 families on shea in three ecozones. They indicated that the majority of the insects encountered were of little significance and would not warrant application of control, with the exception of *Cirina forda* (Saturnidae:lepidoptera) (Figure 7), a major pest causing 60–90% defoliation of mature trees of *V. paradoxa* in the Southern Guinea Savannah. However, herbivory occurs after fruit production, only on old non-photosynthetic leaves and results in brand new foliation (B. Bastide, pers. comm.) and better fruit yields the following year according to farmers (P. Lovett, pers. comm.). The caterpillar provides an incidental source of food to locals. Evaluating its potential as poultry feed in Nigeria, Kenis et al. (2014) showed that it can be substituted in up to 75% of the fish meal intake in broiler chick diets without negative impact on weight gain. Lamien et al. (2008) also identified a shoot and fruit borer, Salebria sp. (Lepidoptera: Pyralidae) in Western Burkina Faso which infected 49–80% of shea trees and 4-15% of fruits.

Figure 7. Intense defoliation of shea by caterpillars of *Cirina butyrospermi* (source: Jules Bayala)

Table 2. Summary of factors influencing fruit yields of shea trees

Factor	Effect	Reference
Inter-annual variation	• Average annual yields of shea stands can vary by a factor of five between years due to alternate bearing	Ruyssen 1957 Boffa et al. 1996
Intra-population variation	• Factor of 5 or more between the best and an average producer	Ruyssen 1957 Boffa et al. 1996
Tree age and diameter	• Yields increase over the tree's 200 year or longer lifetime, • Yet minor effect over small age intervals compared to phenotypic variation • No impact on flowering attributes	Ruyssen 1957; Delolme 1947 Boffa et al. 1996 Kelly et al. 2007
Temperature	• Higher average minimum temperatures during November-February and an early start of flowering period (Oct-Dec) result in higher nut yields. • Bushfires and harmattan wind/dust reduce yields.	Desmarest 1958 Ruyssen 1957
Soil moisture (rainfall)	• No clear effect on its own. Likely interactions with soil and subsoil factors and temperature	Ruyssen 1957; Kelly et al. 2007
Soil fertility	• Shea is apparently adapted to poor shallow soils and areas adapted to rainfed crops. • No significant effect on productivity of matures trees on these soils. • Positive effect of weed control, intercropping with legumes and manure on mature trees. • N and P fertilization stimulates seedling growth in the nursery	Ruyssen 1957 Desmarest 1958; Picasso 1984 Hall et al. 1996 Dianda et al. 2009
Plant hemiparasites	• No difference in yield or flowering parameters between different levels of infestation • Strong impact on tree vigour longevity in the northern drought-affected part of the range	Houehanou et al. 2011; Lamien et al. 2006b Boussim et al. 1993
Pests and diseases	• Insignificant diseases and fungal attacks • Insects, *Cirina forda* and a shoot and fruit borer (*Salebria sp.*) create major damage	Sallé et al. 1991 Odebiyi et al. 2004 Lamien et al. 2008
Parkland management	• Flowering attributes more favourable in farmed parklands than in unmanaged forest • Fruit yield 3 times higher in farmland than in unmanaged forest • Twice as many fruit-bearing trees in parklands as in unmanaged forest • Larger average tree diameter as well as fruit size and weight parameters in parklands than in unmanaged forest	Kelly et al. 2007 Lamien et al. 2004 Lamien et al. 2004 Lamien et al. 2004
Girdling	• Yield increases by 100%. No difference in timing of the technique (August vs. November). No knowledge of long-term impact.	Lamien et al. 2006a

3. Social and institutional dimensions of improved shea management

3.1 Intra-household access rights to shea trees and products

Women's access rights to trees are linked to their overall socio-economic position in the household. In the shea belt, farm households are generally made up of overlapping but semi-autonomous production and consumption units associated through labour-, food-, and/or income-pooling arrangements (Gladwin and McMillan, 1989). In the common extended (polygamous) family model, the household includes "those individuals who farm a communal field under the jurisdiction of the household head, and who eat from the same cooking pot" and may include up to 20-30 members or more. The eldest male allocates cultivation rights on private fields to his wives and married sons who must contribute their labour to communal fields that he manages. Wives and married sons are entitled to the production of their private fields where they can work after fulfilling their responsibilities on communal fields.

Women's responsibilities are focused on the everyday health and hygiene of their family, and especially that of their children. They are responsible for the preparation of meals and related collection of water and firewood. While men provide the staple cereal food and when possible meat and fish, women are responsible for supplying all other ingredients for the sauce, including vegetables, spices and cooking oil. In addition to the staple food, men are generally responsible for cash household expenses for the children's clothes, medicine, transport and school fees. However because men's income is often insufficient, women's activities are critical to the household's survival. Food produced on a woman's field as well as women's sales of shea fruits and butter, soumbala[2], beer, cooked food or petty trade are used to supplement her and her children's consumption during the dry period after cereal harvests from cooperative fields are exhausted, and to generate additional cash for all the above-mentioned expenses (Gausset et al., 2005).

Men benefit indirectly from women's work and appreciate these contributions to household food security (Y. Tomomatsu, pers. comm.). However, 'the behavioural assumption that the household is a husband-wife team maximizing a jointly held utility function to attain shared goals should not obscure both the conflicts and complex complementarities that occur within and divide the household' (Gladwin and McMillan, 1989). Reflecting distinct gender responsibilities, women are interested in trees for the subsistence use of their products for the household, while men see trees as a commercial product (Gausset et al., 2005).

Traditionally, women are entitled to collect the fruits and the value of marketed butter from shea trees growing on their personal fields (Terpend, 1982). The male family head also grants female members of the household the right to gather shea fruits from trees that grow on family fields (Ruyssen 1957; Boffa et al., 1996). Yet with increased population density, pressure on land and the commercialization of tree resources as in the village of Peni, southwestern Burkina Faso, male household heads may strive to assert their claims over trees growing on household fields, by placing charms on néré trees to dissuade collection or complain that their wives are 'stealing' shea nuts (and néré pods) from them (Gausset et al., 2005). Men's claims to these trees may also be enforced through the control of revenues generated. In the Thiougou study, southern Burkina Faso, income from marketed nuts was the single purview of women in 66% of households; it was shared in 27% of them and was entirely claimed by men in 7% of cases. In contrast, Dagomba women's income from shea nuts is not shared with their husbands in Northern Ghana (Y. Tomomatsu, pers. comm.).

Because of men's customary ownership of trees on their land, women rely, to a great extent, on tree resources including shea trees located in fallows and woodland/bush areas where access is open to all, for food and income. This makes resource use rights of women more vulnerable to village-level or

2 *Protein rich product of Parkia biglobosa*

regional trends affecting land use than men's. In South-western Burkina Faso for instance, expansion of cultivated land by migrants, the development of mango and cashew plantations and cattle grazing reduce fallow and bush areas in villages as well as the availability of wild produce and regeneration of useful trees. Increased integration in the market economy and commercialization of tree products also result in increased pressure on resources, more stringent tenure privatization and competition between men and women (Gausset el al., 2005). Women are increasingly seen to cut live trees or branches for firewood instead of harvesting dead wood and young men use traditionally or legally protected species such as locust bean and shea trees to make charcoal.

The decline in cocoa commodity prices or an increase in shea value as seen in Côte d'Ivoire can also lead young men to compete with women and invest time in the collection of shea nuts (Elias and Carney, 2007). Men do not process the nuts, but sell them directly to wholesalers. The job is often done for profit maximizing reasons and collection is done without due regard to quality or postharvest treatments to prevent nut germination and deterioration of fats in the nuts. In the Korogho area of Northern Côte d'Ivoire, the involvement of young men has been seen to result in temporary flooding of local markets with low quality nuts and the decline of shea prices (D. Louppe, pers. comm.).

For reasons presented above, one would expect that the increased availability and cultivation of superior shea varieties that would result from a systematic breeding program may cause the intra-household distribution of rights to shea trees to evolve. Therefore the monitoring of trends regarding women's access rights, the privatization of shea tenure on cultivated land by men and how to encourage their longer-term participation in the shea value chain should be key elements of gender-sensitive shea improvement and development initiatives. However, complementary goals toward household food security between gender groups and traditional self-governance mechanisms at village level (Tomomatsu, 2007) provide opportunities for shea projects to actively support local communities in implementing strategies strengthening women's roles in the management and usufruct of improved shea resources.

3.2 Inter-household access rights to shea trees and shea products: influence of land tenure status and resource commoditization

The labour invested by an ancestor in the first clearing of a piece of land for agriculture confers primary land use rights that are transmitted to his descendants (McMillan, 1986). Such indigenous land right holders generally have primary access to shea nuts in their fields, fallows and woodlands (McLain, 1990b and 1991a; Saul 1988). The latter author adds that, among the Mossi on Burkina Faso's Central Plateau, anybody can eat *V. paradoxa* fruit (sweet outer pulp) as it perishes very quickly after picking, but that the economically important nut has to be left at the foot of the tree. The permanent landholder may also choose to allow anyone (including land borrowers) to gather the nuts. In contrast, in villages south of Bamako, trees on crop fields belong to the cultivating household, but collection of shea nuts is carried out by everyone in the village regardless of field ownership (Gakou et al., 1994). A similar pattern where trees located within or outside cultivated fields would traditionally belong to the community was reported among the Bobos of Koutiala, Mali by Ruyssen (1957), but has probably evolved in recent decades.

Present-day village communities are made up of groups of different origins, indigenous people and migrants. Population expansion, soil fertility decline and in-migration create the need for farmers – indigenous or migrant – to borrow (additional) plots of land for crop cultivation. Borrowing land is traditionally a social capital-building practice with no monetary compensation; in-kind gifts are common but depend on social relations (Sawadogo and Stamm, 2000). The percentage of cultivated area under a borrowed status in villages ranged from 25% to 56% in a series of studies from Burkina Faso and Mali reviewed in Boffa (1999), and 75% of

Diarrassouba et al.'s (2008) farmer survey sample in Côte d'Ivoire fell in this category, indicating the importance of this way of accessing land cultivation rights in West Africa. On lands that have been loaned to them by the local customary chiefs or indigenous land-owning lineages, these farmers usually have weaker access rights to tree fruits while they can access shea trees on surrounding uncultivated lands. However their contribution to the conservation of trees during cultivation is considered and their rights tend to depend on social bonds with those who grant access to land, loan duration, degree of land pressure and the economic value of tree products (McLain, 1990b and 1991a). In Peni, the permanent land right holder may retain the full ownership of all fruits, or share the harvest with the migrant household (Gausset et al., 2003).

Nevertheless, some ambiguity remains in the fact that shea and other parkland trees are protected from nature (and not from plantings like annual crops) but they occur on private fields, and can thus be considered a private value (Gausset et al., 2003). On the ground of their wild status which also applies to other wild products such as game or wild vegetables that are free for all, private claims of indigenous land owners is generally challenged by village women. As a result, shea and néré fruits are often 'stolen' because they are considered a 'wild product', especially if they are situated far away from inhabited areas or on fallow land. Gausset et al. add that 'although it is a net loss for the owner, the theft of néré and karité has the effect of democratizing access to this important resource for all women in the area'.

Similarly, in the densely settled area of Western Dagomba, Northern Ghana, many women who do not have access to a sufficient number of shea trees in their household fields and fallows visit their neighbour's farm to collect nuts. This has resulted in a quasi-rule where an early morning shea nut harvest is reserved for women of the lineage or community holding rights to the land after which a secondary harvest later in the day is allowed for non-right holders (Y. Tomomatsu, pers. comm.; Poudyal, 2011). This arrangement applies to both shea trees on privately owned land as well as fallows.

With new demographic and socio-economic trends including the sale of land to investors as found for instance in south-western Burkina Faso autochthonous residents are now trying to get back the lands they had allocated to migrant communities some years or even decades ago and/or reclaim access to shea products (K. Rousseau, pers. comm.). Therefore tensions and power struggles surrounding access to shea and its products are a reflection of far reaching land tenure changes and ongoing resource competition. These land tenure issues can be quite explosive. In this region land legislation is in place but implementing institutions either do not exist or have been unable to cope and conflicts between customary authorities and centralized or decentralized State organizations are common.

In these conditions the continuum of proprietary arrangements for accessing land (short-term borrowing, long term use agreements, gift, rent, purchase, etc.) and associated rights to trees and their products is evolving rapidly toward greater individualization. As shea products gain value internationally, harvesting pressure increases and access rights are more strictly guarded.

3.3 Tree planting on borrowed land

Land loans are usually not granted for a predefined period, but are continued over time as long as borrowers comply with social obligations with the landowner (symbolic gifts, assistance in key events, respect for totem and religious customs, etc.) and accepted land management practices. Borrowers often cultivated land for two to six years in the Bam Province of Burkina Faso, but longer periods were not uncommon (Savadogo and Stamm, 2000). When farmers clearly explain to their children their non-permanent status, loans could be safely extended to the next generation. However in recent times the lending period has reduced and borrowers are more often shifted from one field to another. Landowners do not object or even expect borrowers' investment in the land and close to 60% of borrowed plots had received erosion control improvements in the above study.

The particular tenure status of tree planting (as opposed to protecting natural regeneration) is related to the principle that 'labour creates rights'. Just as clearing a piece of land confers ownership to the clearer, planted trees in Africa generally belong to the planter and tree planting may give that person rights over the land on which they are planted (Fortmann, 1985). This poses no problems where tree planting is done by permanent land right holders on their land, but it can be used by migrant farmers or other types of borrowers to whom land was granted on a short- or even long-term basis to visibly claim strengthened tenure. Afraid of losing the possibility of deriving benefits from the land where the trees are established, landowners generally outrightly refuse to allow borrowers to plant trees on their lineage land (Neef and Heidhues, 1994; McLain, 1990a; 1990b; 1991b; Swanson, 1979). In fact, in all four areas studied in Central Mali, the number of borrowed agricultural plots with planted trees was significantly lower (half or less) than that of inherited plots with planted trees (McLain, 1991a).

Savadogo and Stamm (2000) stated, "It is not prohibited to plant trees on borrowed land. But before doing so, you have to inform the landowner. This is absolutely necessary to avoid any suspicion". As a result, conflicts may arise from the planting of trees on loaned land without securing the landowner's permission; and owners will go so far as to uproot young trees or migrant farmers may be expelled from their holdings (Swanson, 1979; Janodet, 1990). Even when permission is sought, it is most often denied for fear that it will lead to a land claim.

Therefore, a thorough understanding and consideration of the local patterns of land and tree tenure is a prerequisite for shea improvement and development activities. Caution is needed in selecting participating communities, households and planting locations not to increase social differentiation and resource conflicts between individuals or groups.

Nevertheless, there are numerous cases of borrowers being allowed to plant trees but the choice of species may be limited. Naturally regenerating trees do not generally modify tenure. In contrast, mango trees, being commercially valuable, were the only trees causing land tenure conflicts in Swanson's research area in Burkina Faso as these (especially the grafted ones) are "the only species considered worth planting and caring for". Similarly, Savadogo and Stamm (2000) mentioned restrictions concerning the planting of fruit trees, particularly mango. It is clear that the greater the commercial value of a tree, the stronger the opposition of landowners to allow tree plantations on loaned sites. Authorization to plant trees on borrowed land also occurs in Mali, but exotic fruit tree species such as citrus, guava, and papaya trees are excluded (McLain, 1990a). In the German Projet Agro-Ecologie in Yatenga, Burkina Faso, experience showed that efforts to plant the exotic neem (*Azadirachta indica*) on borrowed land often resulted in the termination of granted cultivation rights. This is not the case for indigenous species (S. Ouédraogo, 1998).

The fact that rights to planted trees may remain ambiguous when owners take back a piece of land can be a disincentive for borrowers to plant trees. However, there are opportunities for landowners and borrowers to reach satisfactory agreements allowing borrowers to benefit from planted trees while safeguarding the owners' rights to the land or that define how tree harvests can be shared between them. Such arrangements are made informally between villagers (McLain, 1991a). In the Bassila area of Benin, farmers who have negotiated authorization with landowners to plant trees in fields, sometimes as boundary markers, chose exotics rather than indigenous species, which could be argued to result from natural regeneration (Schreckenberg, 1996).

A farmer who returns a borrowed field to the landowner may or may not come back every year to gather products of an indigenous (subsistence) tree species he has planted. He would certainly return, however, if the (exotic) tree produced a sizeable marketable harvest such as mangos. The economic value associated with fruit tree plantations is such that land parcels where orchards are established are more and more being treated as personal property. Unlike most other types of land where the principle of inalienability is respected, plantations are increasingly subject to sales (Saul, 1988).

In contrast to “wild” shea which is traditionally self-sown and not planted, the act of planting shea that would result from improvement activities would likely align it to more systematically planted commercial tree species such as mango, cashew, oil palm, etc. Thus, doing so on borrowed land should not be considered a benign activity and would require awareness of potential land tenure conflicts and support in developing equitably negotiated pre-informed agreements between lenders and borrowers of agricultural land.

3.4 Women and tree planting

In patrilineal societies that prevail in shea producing countries, land is allocated to a woman by her husband and its location may change from one year to the next. The lack of tenure security is a disincentive to long-term investments such as tree planting. In addition, tree planting is traditionally done by men and there may be socio-cultural constraints to women participating in tree planting operations. Therefore, women appear quite disadvantaged regarding the potential benefits of an assumed domestication program that would make the planting of improved shea trees possible at village level.

Nevertheless, on the basis of enhancing household food security, projects can influence conditions of women involvement in exchange for the participation of their village in such programs. Deliberately pre-negotiated agreements between men and women of households participating in such programs that would secure access of women to tree production without contesting men’s ownership of the trees may be successfully crafted. Such arrangements will be needed for women to remain empowered in the ‘improved’ shea production sector.

Another strategy pursued by women is to create women’s groups, which have less difficulty in accessing land and creating tree plantations than on an individual basis. Because such groups give the village a good reputation with NGOs or aid agencies, men may also benefit. Moreover, as the fields of the group are shared by all women, and owned and inherited by no one specifically, they do not threaten the existing male-dominated system of land tenure (Gausset et al., 2003).

3.5 Shea resource management and relations to national forest policies

Superimposed on traditional land and tree tenure regimes are forest codes, originally written for the whole of French West Africa. The general trend for administrations was to reduce the influence of customary village authorities over land rights in order to achieve resource management based on centralized state control. More recently, most Sahelian countries have revised their forestry legislation but many basic similarities remain. In principle, the new forest codes go some way towards recognizing customary rights and, in some cases, devolving management of certain forest and parkland resources to local populations. In practice, implementation is complicated by ambiguous definitions of different types of forest resources. Farmland technically falls outside the forest domain, but because rural landholdings are often unregistered, they continue to fall under the state’s control. Thus many restrictions originally intended to protect forest trees are also applied to trees on farms and in fallows, with the result that farmers are prevented from carrying out basic management activities such as pruning, thinning or coppicing, which are crucial in optimizing their land use systems.

Forest codes are often poorly understood by rural people and forest agents alike. Faced with a lack of human and financial resources, most forest services are unable to enforce regulations properly, and individual agents often take the option of interpreting obscure permit requirements to their own benefit in order to supplement their meagre salaries. This serves to further discourage farmers, for whom forest agents are among the most disliked of government officials. Moves to encourage and officially recognize local management of resources will need to be accompanied by institutional change within forest administrations with far greater emphasis given to training of staff in participatory approaches and acknowledgement of the often sustainable nature of traditional management practices.

3.6 What is the demand for the improvement of shea?

As mentioned in the introduction, researchers are concerned about the sustainability of shea populations over its range. These relate to population pressure leading to land clearing, the southward shift of tree species due to climatic shifts (Gonzalez, 2012; Maranz, 2009), the extension of cultivation periods and the declining or discontinued practice of fallow which allows parkland regeneration, density decline (Gijsbers et al., 1994; Boffa, 1995; Djossa et al., 2008), ageing and low regeneration rates of shea stands (Raebild et al., 2012), and overextraction of shea trees for fuel (Louppe, 1994; Mapomgmetsem et al., 2011). In addition, the deliberate stumping of trees (removal of roots, as opposed to just cutting) for intensive and mechanized farming was the third most important threat to shea trees on farmland perceived by women respondents in Northern Ghana (Poudyal, 2011; A. Perinic; P. Lovett, pers. comm.).

Being central participants in the interface between supply and demand for shea, the views of the shea industry on the need for increased production and improvement of shea are also valuable. The following questions may be relevant to understanding potential levers and demand for the shea resource improvement:

- Has demand ever exceeded supply in the history of the crop and is a potential shortage in supply a concern given the large production potential of *Vitellaria*?
- Are all *Vitellaria* populations being exploited for the export market and how is the supply being affected by improved access to 'new' production areas, for instance through the construction of new roads?
- Is the storage capacity at village level and by industries sufficient to respond to increased demand and shield from price increases caused by the large annual fluctuations in supply?

In turn, how does the lower industrial demand in the chocolate sector for shea nuts produced in the central and eastern parts of the range (Eastern Nigeria to Uganda), where olein content of shea fat is high (Maranz et al., 2004), influence incentives for the management of shea parklands?

There are indications, some of which are however dated, that both potential and actual supplies of *V. paradoxa* kernels in West Africa exceed local and international demand. In Mali, only 39% of nuts were collected in the 1970s (Hyman, 1991). Richard (1980) estimated that roughly half of the 40-50,000 tons of the *Vitellaria* kernels which Côte d'Ivoire could produce was exploited. According to Lovett (2004), about half of the total available potential shea production in peak years in the major West African producing countries was uncollected and remained unused. At the farm level, the comparison of actual yield measurements from a sample of over 50 trees in bush fields in Southern Burkina Faso and collected amounts as stated by farmers in 1993, a low production year, showed that half or less of nut production was harvested (Boffa et al., 1996). Likewise, only an estimated 5-10% of the potential harvest was gathered by villagers in Benin in 1993, despite the fact that *Vitellaria* was the most valued non-timber forest product species in these villages (Schreckenberg, 1996), suggesting that farmers were not fully utilizing the resource. Could efforts to reduce the underutilization of shea harvests help or even be sufficient to meet the increasing demand for shea products over coming years, thus making resource improvement less of a priority? Furthermore, could shea's improvement lead to greater local utilization?

One may then ask: What factors prevent women farmers from collecting more of the shea nuts from trees they have access to? Under-collection relative to production of shea nuts appears to be governed by a complex relationship between labour availability for gathering and/or processing relative to other activities and selling price (Boffa, 1999).

Figure 8. Headload transport of goods by foot in shea parklands is a time-consuming activity for women (source: Global Shea Alliance)

It is a challenge for women to increase nut collection during annual periods of peak workloads and when shea-related activities therefore compete with their other productive activities (Figure 8), including the preparation and sowing of family and their individual fields that will produce the bulk of household annual cereal security. While early season nuts are wet and plentiful and attract low prices, the high-price trade for exported dry shea kernels does not begin until at least three or four months after the peak harvest (Lovett, 2004). The inter-annual and intra-population variability of production is a disincentive to collection, as indicated by the fact that no collection was undertaken in 5 and 27 fields from a sample of 65 fields in a high and low production year, respectively, in Boffa et al.'s study (1996). Introduction of improved shea varieties would reduce tree-to-tree yield variability and annual variation patterns may be at least partially addressed through improved cultural practices. Improved shea stands in parklands would be planted in closer proximity to the compound. Their incorporation would thus bring the shea resource closer to women and reduce their walking and collection time.

Information on costs and benefits, both economic and non-monetary, of competing demands on women's time and opportunities is key to better understand how shea collection activities could be expanded and their profitability enhanced in relation to other options. Research is needed on the opportunity costs of women's time in shea-related activities in comparison with concurrent household and individual subsistence activities, child care and other potential income-generating activities. Various surveys (Pouliot, 2012) have established that a large majority (94%) of rural households in the shea belt are involved in collection of shea nuts and fewer in the commercialization of shea products (59%). The above-mentioned research activities would lead to insights into possibilities of relieving women's time and lift constraints for their greater involvement in shea nut collection and processing.

Access rights to shea trees and characteristics of the tree resource base (location, density and productivity) appear to be two key governing aspects. The latter has been reviewed in section 2 above. Factors which positively influenced the selection of shea butter production as a livelihood activity in Burkina Faso (that are likely to apply elsewhere) included the extent of land area owned by the household and its ownership of productive assets (for instance, means to transport nuts) (Pouliot and Elias, 2013). These would similarly be associated with greater household involvement in shea nut collection and post-harvest processing. Nuts are collected from fields, fallows and uncultivated bush land (Figure 9). A household with a larger agricultural land area will have direct access to a larger number of shea trees. Nuts from these trees are usually gathered and piled up by women at the bottom of trees during cultivation work in the field and carried back home at the end of the day. The opportunity cost of gathering nuts in such manner is low and as a result, shea nuts found in farmed fields may frequently be collected in their entirety (Elias, 2010 in Pouliot and Elias, 2013). However, Pouliot and Elias (2013) found that the size of family landholding was not significantly correlated with its shea income. They suggested that it is women's decision to invest labour in gathering shea nuts from distant areas in addition to the opportunistic collection in fields and their post-harvest processing that leads to greater returns. Ways of making the collection and transport of shea nuts and fuelwood, and water provision for boiling fresh nuts less time-consuming, easier and safer, reducing fuel and water consumption (Section F.1) and improving drying techniques for freshly boiled nuts should be discussed and developed in close consultation with local women. Interventions could therefore focus on the conditions and modalities of improving women's access to bicycles, donkey carts, and appropriate and viable anti-venom at decentralized centres, where training tools and information on collection and processing could also be disseminated.

Figure 9. Collection of fallen shea fruits (source: Global Shea Alliance)

In order to better understand determinants affecting participation in collection and marketing of shea nuts, information is needed on women's labour investment, nut collection and commercialization strategies for the local market/home consumption or traders according to specific household (age, education level, level of household responsibilities, etc.) and village circumstances as well as factors dictating the relative share of household nut collection undertaken in fields, fallows and bush land and their location in villages. Also, while a relatively large body of generic information is available on the types of tree tenure regarding shea and drivers of change, little detailed research has been undertaken on constraints and drivers of tree tenure patterns on lineage or privately owned land among individuals within extended households (Tomomatsu, pers. comm.). Investigating specific tenurial arrangements that govern access to shea trees in other parts of the village landscape would also provide useful information in the study of household shea nut collection strategies.

Profitability and receipt of total perceived benefits, the second major drivers of women's time investment in shea nut collection are key motivations of households for sustaining shea parklands. However relatively little economic data are available on prices offered to women shea nut collectors in relation to quality of shea nuts in the various value chains (cosmetic and food industries; local and export markets) and the price structure in these chains. This deserves greater research investment if one keeps in mind that higher revenue received by collectors is a direct and positive reinforcing factor for sustainable shea parkland management decisions.

Louppe (1994) reported that women in Northern Côte d'Ivoire sold their nuts to traders at the price of 15 FCFA/kg and that the harvesting and proper preparation of dry nuts ready for commercialization including boiling, depulping, drying and shelling takes one hour per kg of nuts. This very low return on their time investment was the reason for the very poor quality of nuts traded for in-country industrial processing or export he observed, compared to those intended for home consumption and local markets. A shea nut supply line thus includes shea nuts of 'any' quality sold by women probably at lowest prices into the local market, which, after multiple consolidation steps, end up trading into industrial scale factories. These batches would include nuts, often of low quality (high moisture content) that women in severe need of cash sell shortly after harvest when seasonal prices are lowest (Pouliot, 2012). In contrast women who can afford holding on to their stocks for some time keep these nuts of best quality and longest shelf life for home consumption, local market butter sales or end of season premium prices.

Quality of raw nuts is not critical to the agri-food shea industry, making rewards for quality unnecessary (Rousseau et al., 2015). Wholesalers or lower levels of buyers in the shea nut commercialization system described by Louppe (1994) in Côte d'Ivoire mention that industrial processors or exporters do not reward quality nuts with higher prices. Thus traders deliberately mix black fungal-infected nuts in batches resulting in a low proportion of good-quality, clean dry shea nuts (less than 20% according to them). This is to bring the 'bulk' quality up and therefore get better prices for the majority of their sales, rather than only better prices for 'quality' nuts. Industrial processors also want consistent quality for uniform processing and factory operation. Since there has traditionally been mixing of good and bad nuts, and because there are few 'standardized' opportunities (or enforceable grading systems) for quality-price differentiation, all nuts are brought to market and base-level prices paid regardless of their quality.

The upstream shea nut supply chain in South-western Burkina Faso, which may be a regional hub for the West African shea market, is structured as a 3-6-step pyramid from collectors to exporters (Rousseau et al., 2015). Shea exports are controlled by a few international CBE manufacturers who contract and pre-finance a relatively small number of wholesalers. In turn, wholesalers pre-finance region-level traders who themselves work with province-level retailers. The latter purchase nuts from highly mobile, municipal-level village traders or local farmers, who source shea directly from individual producers in the countryside and local markets.

In individual transactions, terms of purchases with these local traders who are equipped with unilateral information on market conditions and prices, as well as cash, can be arbitrary and inequitable. During the hungry season, women's short-term financial needs put them in a position of price takers (François et al., 2009). These well-established and efficiently coordinated networks of traders (Rousseau et al., 2015) exercise a downward pressure on shea prices (Chalfin, 2004 in Greig, 2006) in an effort to cover storage and transport costs. However, they play a useful and important role in collecting and bundling shea production over large rural areas where supply is fragmented over thousands of shea producing households who are largely unorganized, and the market is characterized by small individual volumes, long distances to main markets, and poor quality roads (Rousseau et al., 2015).

In parallel, there has been a strong growth in direct linkages between women co-operatives and niche markets in the international cosmetics industry in an effort to enhance returns to women producers for higher quality shea products (Sidibe et al., 2012). Prices vary depending on clients and the quality of butter produced with premiums offered in traceable production chains. Francois et al. (2009) report price differences of CFAF 1,000-1,200/kg for regular butter and CFAF 2,500/kg for traceable organic butter in Ouagadougou. Elsewhere in Burkina Faso producers earned USD 4.96 per kg of butter sold on FLO-cert contracts, as compared to USD 2.07–3.11 per kg on the conventional international market (Pouliot and Elias, 2013).

3.7 Planting "wild" and "improved" shea

Probably one of the greatest barriers toward the conventional improvement of the shea crop and its transformation into a plantation crop is the lack of a planting culture for indigenous tree species in the region (Lovett, pers. comm.). Baobab (*Adansonia digitata*) may be an exception. At the same time, because shea is such an important species for local livelihoods, it features in the top group of tree species lists prioritized by farmers across its distribution area (Kalinganire et al., 2007). Farmers generally express their keen interest in integrating improved shea varieties into their farms *if they were available*; thus providing a strong justification for shea improvement programs.

In northern Ghana and elsewhere, there are taboos against planting trees and shea specifically. Diarrassouba et al. (2008) refers to legends in Côte d'Ivoire that 'someone who plants a shea tree will die when the tree starts fruiting'. Yet farmers tend to recognize that such beliefs are things of the past (Hansen et al., 2012). As an indigenous species, *Vitellaria paradoxa* is very rarely planted because of social customs and the perceived long time it takes to reach maturity and yield expected benefits. Rural people consider it a gift of nature and because it is self-sown and abundant in the vegetation they do not spontaneously invest time or resources planting the tree. According to a study focused on shea and locust bean (*Parkia biglobosa*) tree tenure in Northern Ghana, all 80 farmers participating in the survey declared having unrestricted rights to plant shea trees on their land, yet, only one of them had ever planted shea. Similarly, only 3% of respondents in the Northern and upper East regions of Ghana reported planting shea on their farmland (Hansen et al., 2012). Instead, (as discussed in section E.1) the 'cultivation' of shea takes place through widespread 'unconscious' selection (or semi-domestication) through the protection of superior individuals and removal of undesired trees during successive cropping and fallow cycles (Lovett and Haq, 2000).

In contrast, there are abundant examples of rural people planting exotic trees (McLain, 1991a; Gijsbers et al., 1994; Hansen et al., 2012). This is mostly done in the vicinity of family compounds, where the benefits of their investment are guaranteed because browsing by animals, fire and harvesting can be controlled and where the use of household refuse, animal manure and plant residues contribute to higher soil fertility than in distant fields.

As opposed to the ratio of farmers (1 out of 80) who planted shea in Poudyal's study cited above, all 80 respondents declared they would plant shea trees on their farmlands if *improved varieties were available* (Poudyal, 2011). Farmers are assumedly interested in planting 'improved shea' on the expectation that the tree would yield heightened economic benefits and would – like other exotic tree species – clearly distinguish planted individuals from all other naturally regenerated shea trees, thus visually clarifying the associated tenurial and usufruct rights of the planter. Based on these reports and discussions with farmers, it is posited that in order for a local planting culture to develop for shea, improvement programs would need to succeed in radically transforming the tree and people's perceptions from what is currently considered a 'wild' tree into the equivalent of an improved, highly productive 'exotic' tree. This mental shift can be made possible by significantly improving its economic performance and appearance, for instance in terms of shortened time to fruition, increased productivity and display of desired (fruit, nut, fat composition of nuts, etc.) characteristics as well as its size and shape. Introduced mango varieties easily distinguished from local mango stock are a successful example of wide distribution in Francophone West Africa (Rey et al., 2004). In several places, farmers recognize local provenances of shea fruits the size of a fist with thick and sweet fruit pulp, large nuts and high-quality fat composition, that are worth flagging more widely as examples of what improvement programs can help multiply on a larger scale (S. Maranz, pers. comm.).

In a participatory shea improvement program, farmers would decide what traits should be sought while considering various market demands. They will also adapt the management of improved shea trees according to their evolving farming systems and needs. Reflecting current tree planting practices, farmers will be interested in introducing these improved shea trees nearer to their compounds like other exotic trees where they can best be protected and nurtured. Depending on the scale and rate of progress over time, one may ask what impacts the introduction of improved shea will have in local farming systems over time. What consequences would these introductions have on farmer perceptions of naturally regenerated 'unimproved' shea stands found in their fields, fallows and uncultivated areas? Over the long term, could the reliance on a smaller number of improved trees to meet subsistence and commercial needs substitute for the maintenance of the more extensive present populations which play a fundamental role in maintaining environmental sustainability of local farming systems?

Based on past tree domestication experiences in other species, adoption rates of improved shea may be slow and above-mentioned risks of competition between a 'wild' (or semi-domesticated) and an improved shea may be low. Based upon successful experimentation by early adopters and dissemination of information regarding improved shea, farmers would probably build a new mindset over time regarding an 'improved' or 'exotic' shea in addition (rather than in substitution) to current norms regarding the 'wild' (or semi-domesticated) shea. As a culture of indigenous tree planting and linkages to markets develop, opportunities for increased land use intensity and concurrent changes in the wider parkland landscape may be expected.

An important aspect of the shea development strategy will be to ensure that farmers do not lose interest in the management of unimproved shea trees found in the rest of their farming landscape (more distant fields, fallows, bush and forest areas) and promote a menu of complementary improved parkland management activities at the scale of whole villages including cultivated and fallow lands as well as woodlands.

Therefore, much research is still needed to better understand why local people do not plant indigenous trees and shea specifically. Programs are needed to address perceived constraints and hurdles to tree-planting in terms of germplasm supply systems, costs-benefits, yield, tenure, cultural aspects, silvicultural knowledge, etc., while identifying factors that would encourage planting and learning from available experiences. In what conditions has tree-planting happened in the past, what steps and incentives would be needed to support such evolutions, what changes and impacts shea planting initiatives may bring about in terms of income growth and improved market linkages, inter-household and gender equity in access rights to trees and land, etc. This is also increasingly true for other indigenous species which can produce firewood and charcoal to relieve pressure on shea populations and other non-timber forest products such as fruit, protein-rich seeds, etc.

Due to the long gestation period of shea and complex bundles of rights to land and shea trees, Rousseau et al. (2015) argue that it would be expensive and risky for agri-food companies to invest in shea plantations. Indeed only a few instances of plantations exist and most are research-oriented. In Burkina Faso for instance a private plantation in Kokologho, the plantation in Niangoloko dating back to the Institut de Recherches sur les Huiles et Oléagineux in the 1940s, that in Saponé in 1987 and a participatory selection trial of 5 provenances from 3 countries planted at Gonsé in 1997. In Mali, a collection of 110 plus trees (clones) from Burkina Faso, Benin, Nigeria, Ghana, Cameroun, Niger and Mali was established at the Samanko research station by ICRAF. Project experiences that have promoted the planting of shea regarding the targeting of local participation, local perceptions of trees as well as land and tree tenure aspects and the lessons they have generated need to be shared.

Because of the profound changes needed in local mentalities regarding the planting of shea, improvement programs will require education, sensitization and the promotion of tree planting behaviour starting with young generations in school curricula. To bypass complexities related to land and tree tenure, projects should be undertaken to demonstrate the feasibility of planting shea in public areas of neutral tenure status such as school grounds, hospitals and urban recreational areas. Initiatives by respected individuals will also have strong demonstration value to encourage farmer adoption; therefore champions with high visibility (national and local political leaders, etc.) should be targeted for leading these initiatives.

4. Technical innovations for resource improvement

a. Parkland management and regeneration

Farmers are primarily responsible for the establishment and management of shea parklands which take place when fields are cleared and useful trees are selectively protected from the natural vegetation and during later clearings after fields have been fallowed for some years. As a central process in shea parkland development, fallow helps to rejuvenate tree populations, following the establishment and recruitment of young trees into the population, and broaden species richness (Figure 10). When they are sufficiently long, traditionally over 15 years old, fallows allow the development of a large number of shea seedlings and also a significant number of several metre-tall saplings which can readily be selected when a new cropping cycle is started (Kaboré et al., 2012). Shorter fallows also provide a pool of new shea recruits which can be selected when starting the next cycle of field cultivation.

Figure 10. Different shea tree ages and species associated with crops (spot the rainbow!) (source: Peter Lovett)

Population pressure on agricultural lands in the Sudanian and Savannah ecozones of West Africa leads to the extension of cultivation periods and the shortening of fallow duration. Where fields are cultivated for long periods (i.e. 15 years) without fallow cycles, densities of mature shea trees in fields tend to decline due to natural death or felling (Boffa, 1995; Kaboré et al., 2012). In older fields the number of young shea trees are also very limited. While new seedlings appear fairly regularly they are subject to various threats (fire, drought, etc.) and not deliberately protected during field operations. The long gestation period before trees become productive discourages farmers from protecting and letting them grow to sapling size. In areas where fallow periods have significantly declined or completely disappeared, shea regeneration will mostly occur under the crowns of existing shea or other trees where bats carry them to in fields. Thus farmers will increasingly need to carefully select, stake, protect from grazing, tillage and fire and possibly water, fertilize and transplant them to suitable locations on their farm to reach regular spatial arrangements that favour uniform insulation and microclimatic effects.

Efforts in mutual learning and sensitization with farmers about current trends and impacts of demographic pressure on land management practices, and the need to adapt tree management practices in order to ensure a sustainable future to shea parklands are essential. Formats for these initiatives may include radio messages, ICT-shared videos, training sessions and posters.

b. Other regeneration techniques

While direct seeding can be difficult due to the short period of seed viability, sowing shea seeds under shrubs as a way to provide protection and more favourable moisture conditions is a technique that is giving good results in the FCN/CAADP project in Burkina Faso (B. Bastide, pers. comm.). Wildings found in fallows and under shea canopies sometimes in high densities can also be successfully transplanted to more favourable sites where they can be given proper care or areas where farmers wish to increase tree densities. Transplanting is done immediately after extraction of a large root ball during the rainy season to minimize stress to the plant.

Figure 11. Grafted wilding in the field with leaf growth (source: Brigitte Bastide)

Shea also coppices readily and vigorous shoots that sprout from coppiced mature trees can be selected, as a way of tree rejuvenation. Induction of root suckering is usually not easy.

Experience with pruning of shea trees infected by Tapinanthus parasites as recommended by Samaké et al. (2011) has been positive with active regrowth of shea foliage (B. Bastide, pers. comm.). Infested branches should be cut before the rainy season above the insertion point of the plant parasite to ensure the removal of the parasite absorption system. The impact of such cuts in the drier part of the shea range should also be assessed (Boussim et al., 1993).

c. Vegetative propagation

The long juvenile phase (period before flowering) of *Vitellaria paradoxa* that lasts anywhere from 10 to 25 years has traditionally deterred farmers from cultivating the tree and explains why its nuts are still collected 'from the wild' despite its strong social and economic importance. Tree growth from seed is slow, reaches maturity after approximately 30 years and has a long average life span of 250 years. The difficulty involved in vegetatively propagating shea trees has also limited the cultivation of superior high-yielding and early-maturing types, and has hindered its domestication.

Stem cuttings. Vegetative propagation methods that allow the rapid and large-scale multiplication of individuals of superior quality are key to tree improvement and conservation strategies, including those for shea. Cultivars can be developed to increase production of shea fruits and nuts with desired traits (for instance, large and sweet fruits, nuts with high stearin oil content and quality) to enhance benefits to local people in terms of food security, income and environmental services. Ideally, one would want to use propagation by cuttings because this technique allows the most cost-effective production of mass numbers of plants. However, the main obstacle of current propagation techniques by cuttings is their poor rooting performance.

Lovett (2000), Opoku-Ameyaw et al. (2000) and Ouana (2001) showed that stem cuttings from coppiced shea nut trees had higher rooting ability than soft or semi-hardwood cuttings with an average rooting success of 60% using the polythene propagator (Leakey et al., 1994). Yeboah et al. (2009a) confirmed this finding about the most conducive type of cuttings for rooting, assumedly due to juvenile status and high levels of auxins in the shoots that enhance rooting, and documented the positive effect of dipping cuttings in 15% sucrose (carbohydrate helps in auxin transport as well as growth of shoots and roots) and in rooting hormone IBA. There was a positive interaction between the three factors. In a parallel experiment, the same authors found that rice husk medium was best for rooting cuttings compared to topsoil or topsoil and sand and that leaching cuttings in water for 24 hours reduced rooting performance (Yeboah et al., 2009b). Susceptibility to fungal attacks is a major issue in the performance of shea cuttings. Thus Yeboah et al. (2011a) tested the effect of four fungicides, optimal concentrations and frequency in association with IBA. The most effective combination recommended was that shea stem cuttings should be dipped in Seradix 3 (IBA) hormone and sprayed three times with Dithane M45 at 2000ppm to enhance rooting and control fungal infection. Retaining petioles, irrigation once daily, using a propagating bin (superior to polythene propagator and polythene tunnel) in addition to IBA were also favourable to rooting and low fungal infection (Yeboah et al., 2011b). Among IBA concentrations, 3000ppm was the most effective option (57.5%) and younger rejuvenated shoots (4-month old rather than 1 to 2 years old) also rooted better (Akakpo et al., 2014).

Air Layering. Success with air layering (the rooting of a branch by peeling off a piece of bark and applying a soil and moss mixture which is then severed from the tree and planted) is generally low. Rates of 33.3% and 22.2% success were achieved respectively with softwood and semi-hardwood at the Cocoa Research Institute of Ghana substation, Bole in Ghana (Opoku-Ameyaw et al., 1996 in Yeboah et al., 2011a), yet it cannot easily be implemented on a large scale by farmers.

Grafting. Grafting has the advantage of involving the use of scions from reproductively mature crowns of large trees and thus greatly shortening the juvenile phase of trees. Relatively high rates of success were obtained with five methods of grafting used on shea wildings in farmers' fields in Mali and Burkina Faso: side cleft (86.1% rate of success), side tongue (80.9%), top cleft (78.1%), chip budding (38.1%) and side veneer (20.7%) (Sanou et al., 2004). The survival and growth rates of grafts showed strong seasonality, with low performance in July (during the rainy season) and highest in January (for survival only) and May (for both survival and growth). January as the bud break period when growth hormones that induce differentiation of vascular elements in the graft tissues are concentrated in buds appears conducive. High meristematic activity during the change of seasons (dry to rainy season) in May favours rapid scion-rootstock union. Two years after grafting, two side veneer grafts flowered and produced fruits in this particular study.

Figure 12. Two(+)-year old shea seedlings in local nursery (source: Peter Lovett)

These results are encouraging and are being used in the FCN/CAADP project in Burkina Faso focusing on the on-farm extension of available research results to control parkland degradation and ageing (B. Bastide, pers. comm.) (Figure 11). Grafting success rates in the project are currently much lower indicating that implementation modalities still need to be improved and mainstreamed. Technical knowledge and tools are positively appropriated by women groups trained in the implementation of the technique, indicating a potential for large-scale dissemination. Nevertheless large-scale application is constrained by its low efficiency (limited number of grafted plants per day), plants cannot be transported, the resource is liable to disturbance (fire, livestock, damage by children, etc.) and ample training is needed.

Figure 13. The burying of the plumule (the bud of the ascending axis of the plant) in shea's cryptogeal germination results in longer time in the nursery (source: Jean-Marc Boffa)

Its potential reach will significantly increase when the technique can be routinely associated with rapid shea seedling propagation in the nursery. Despite the lack of recently published data, nursery production of shea seedlings to a stage when they are ready for grafting currently takes two years (Figures 12 and 13). An additional year is recommended for hardening after grafting. From the time of establishment, fruiting of these seedlings will take a minimum of 5 to 7 years or a period of 8 to 10 years in total and fruit production will become significant after several additional years (C. Dembélé, pers. comm.). Intensification of shea production would require a shorter generation period. Research is therefore needed to investigate ways of significantly shortening the nursery production cycle and mainstreaming such modalities.

Micropropagation. Rooting performance of explants used in conventional vegetative propagation techniques (cuttings, air layering) of woody species is often poor. These techniques tend to promote root systems with no tap roots;

thus propagated plants may not withstand extreme weather after transplanting. *In vitro* propagation and specifically somatic embryogenesis would seem to provide an effective means of mass production of plants with tap root systems (Lovett, 2000; Fotso et al., 2008). Somatic embryogenesis for shea would allow the large-scale clonal propagation of pre-selected superior genotypes, the rapid production of high quality planting material for farmers, and contribute to conservation of the species. Development of *in vitro* propagation techniques should therefore be a key ingredient of a portfolio of research activities for shea domestication.

A few studies have been undertaken to analyse the response of shea explants to different concentrations and combinations of plant growth regulators and culture conditions in terms of callus formation, shoot regeneration and rooting. Plant growth regulators include cytokinins (BA: 6-benzyladenine; BAP: 6-benzylaminopurine) and auxins (NAA: napthaleneacetic acid; 2,4-D: 2,4-dichlorophénoxyacetic acid; IBA: indole 3-butyric acid). The Fotso et al. team (2008) first achieved initial stages of somatic embryogenesis in *Vitellaria paradox*a leaf fragments from a single shea tree. Using a ratio of BAP/2,4-D of 0.5/3, a rate of 87.3% callogenesis was achieved in 28 days. Induction of differentiated somatic embryos was obtained with a combination of 0.5/2 BAP/2.4-D leading to 62.1% calli developing embryos over 97 days of culture with an average of 27 embryos per callus. However, they were unable to induce fully formed shoots or roots.

Adu-Gyamfi et al. (2012) successfully germinated somatic embryos from embryogenic callus of immature cotyledon explants from a single shea tree. These bipolar embryos subsequently developed shoots and roots, and transplanted plantlets acclimatised. Shea regeneration through in-vitro culture can thus be achieved. Their work emphasized the role of 2,4-D in inducing embroyogenic callus in shea, albeit at very low concentrations (0.45 μM). The subsequent development of somatic embryos once separated from calli was favoured by an auxin-free medium in the dark. Their study provides a successful protocol for somatic embryogenesis and plant regeneration of shea. However, the low germination success rate of 15% obtained calls for further work to optimize culture conditions. Lovett (2000)/Lovett and Haq's (2013) study differed from the previous two in using apical shoot tips as explants and in that, these were grown from seeds originating from randomly selected shea trees. Response of explants to different concentrations and combinations of the plant growth regulators BA and NAA was variable. They observed that axillary shoot formation peaked with cytokinin (BA)/auxin (NAA) ratios between 5:1 and 50:1. Frequency of root formation with the presence of IBA was only 16% and occurred between 90 and 120 days after cutting. Their study, that of Issali et al. (2013) who obtained varying callogenic response from immature fruit mesocarp in seven shea genotypes, and in vitro culture studies conducted on other species of the Sapotaceae family all suggest that responsiveness to micro-propagation can differ according to shea genotypes. Based on other studies, Lovett and Haq (2013) also mentioned that the cytokinin/auxin ratio necessary for shoot proliferation may be high while root formation may be most effectively induced with high auxin/cytokinin levels. They hypothesized that together, hormone concentration ratios and genotype may explain much of the variation observed in the *in vitro* performance of shea.

Collaboration with Nestlé Africa equipped with a massive industrial tissue culture facility where they mass-propagate cocoa outside Abidjan might be interesting in order to upscale *in vitro* shea production once shea micropropagation techniques are sufficiently mainstreamed (S. Maranz, pers. comm.).

d. Improved tree management

Tree crown pruning

Shea can be rejuvenated by crown pruning yet not without negative fruit yield impact over a period of five years. In totally pruned (reducing all of the secondary branches to one metre from their base) mature trees of 50cm average dbh fruit production recovered by 83% 5 years after pruning and fully 6 years after pruning. However, cumulated yields were halved over that period. Crowns recovered by 73% over the period. Fruit yields did not differ significantly between unpruned and half-pruned trees (Bayala et al., 2008). Short-term millet production was improved in the process (Bayala et al., 2002) (Figure 14).

Figure 14. Improved sorghum production under a heavily pruned shea tree (source: Jules Bayala)

Fertilization

Little research has been conducted on the potential of fertilization for improving tree growth and fruit production of shea. Weed control by hoeing, intercropping beans and manure application had positive effects on fruit yields (Hall et al., 1996). N and P fertilization in nursery conducted by Dianda et al. (2009) stimulated the growth of 6-month old shea seedlings but response depended on the ratios between both nutrients. N limitations appeared to be the main constraint to biomass accumulation. When investigating the N requirements for optimal growth of shea seedlings, N dosage much lower than 12 $mg.kg^{-1}$ should be used under conditions of P shortage. External N inputs relative to P supply and possibly soil K concentration was recommended for successfully using mineral fertilizers in shea nursery production. This experiment also showed that shea is a susceptible host species to the arbuscular mycorrhizal (AM) fungus *Glomus intraradices*, yet no benefits of AM fungi inoculation to seedling growth were evident, probably because no P stress occurred. Such colonization and nutrient uptake experiments undertaken by Dianda et al. (2009) need to be expanded to a wider range of mycorrhizal fungal strains in order to accelerate tree growth. A great deal more research work is also needed on identifying appropriate shea fertilization regimes for soil conditions found in the region to stimulate both seedling growth and fruit production of trees.

Cultivation of shade-tolerant crops under trees

Because of food security imperatives under growing population density, the ways in which shea trees combine with local crop production in current parkland or improved configurations are important incentives to consider. Plants utilizing the C4 photosynthetic pathway (such as maize, sorghum, millet) require higher sunlight intensity than C3 crops. In most cases yields of these cereal crops are reduced under tree crowns compared to growing conditions in the open. A few studies have tested the association of C3 crops such as taro, pepper, chilli pepper, and eggplant with shea and other trees and show a positive, neutral or less negative influence on these crops than locally grown cereals. The beneficial effect of intercropping cereals and legumes can also be more pronounced under trees than in treeless locations. An opportunity therefore exists for increasing and diversifying crop production by targeting shade-adapted crop species to growing conditions found in the vicinity of shea and other trees. Such adaptations resulting in lower tree-crop competition could lead to changing farmer perception of trees in fields. To better assess and reach this potential additional work is needed on a wider range of C3 crops planted under shea monitoring performance over several seasons and under varying agroecological conditions.

e. Diversity analysis and domestication efforts

Within the *Vitellaria* species, two subspecies have been distinguished, *V. paradoxa* subsp. *paradoxa* and *V. paradoxa* subsp. *nilotica* (Hall et al., 1996). There are morphological distinctions and the two subspecies are separated by geographical area of distribution, subsp. *nilotica* in the Eastern part and subsp. *paradoxa* in the Western part.

In terms of genetic diversity, Fontaine et al.'s (2004) study suggested a genetic differentiation between Eastern and Western African shea populations which emphasized the separating role of the Dahomey Gap, a North to South savanna corridor that appeared in the late Holocene (B3000 years ago) in Togo and Benin. Allal et al. (2011) also identified two major genetic groups geographically separated by the Adamawa Highlands: a 'West' group, that is relatively homogeneous over the 3000km area comprising West Africa, and an 'East' group which however was divided into two subgroups purported to be a result of glacial climatic perturbations. They also observed high but poorly structured levels of diversity in West African populations, probably resulting from the intense human activity in this area and recommended focused conservation efforts in this part of the shea range to capture this diversity. Most of the variation is found amongst individuals within populations, indicating that sampling for the development of *Vitellaria paradoxa* breeding population should consist of many individual trees selected within a few populations to capture a large proportion of variation (Bouvet et al., 2004). Investigating the impact of human activity on the spatial and temporal genetic structure of *Vitellaria*, Kelly et al. (2004) found weak differentiation of forest and fallow stands within each cohort (adults, juveniles and regeneration) suggesting extensive gene flow between these populations.

A significant number of studies have assessed qualitative and quantitative traits in shea's morphological diversity. Qualitative traits comprise tree shape, fruit shape and colour of the nuts while quantitative measurements are taken on various characteristics of trunk, canopy, leaves, fruits, nuts, and coordinates of location. Studies include Lovett and Haq (2000b) in Ghana, Diarrassouba et al. (2007) in Cameroon, Diarrassouba et al. (2009) in Côte d'Ivoire, Mbaiguinam et al. (2007) in Chad, Ugese et al. (2010) in Nigeria, Sanou et al. (2006) in Mali and Gwali et al. (2014) in Uganda. They show the large amount of diversity in these characters in shea populations across the range.

Studies evaluating the diversity in early growth performance and water use of shea provenances can help identify those most suited to specific climatic conditions in the distribution range (Bayala et al., 2009; Ugese et al., 2011).

Knowledge of shea butter fat content and composition is key to its economic importance for food and cosmetic industries. Kernel fat content range varies generally between 20% and 50% (Maranz et al., 2004). Fatty acid composition of shea butter is dominated by stearic (25-50%) and oleic (37-62%) acids. Their relative composition directly influences the consistency of shea butter. Ugandan shea populations produce consistently high oleic acid butter (51.2-62.1%) that is liquid, while West African is much more variable, with an oleic acid content ranging from 37.1-54.7% and with soft and hard consistencies produced within the same local populations. Shea trees on the Mossi Plateau in Burkina Faso and Northern Ghana produce the hardest butter. Shea butter also contains 5-15% unsaponifiables, including phytosterols, triterpenes and hydrocarbons which are central to quality for cosmetic use.

More research is needed for understanding the environmental and genetic basis of variation patterns in the fat composition of shea nuts. Like all oilseeds, shea nuts have a basic chemical profile that is genetically determined, although the relative proportion of different compounds commonly varies, which can be understood as an interaction between genetics and environment. For instance, while all shea butter contains primarily stearic and oleic acids, shea butter from the hot West African lowlands has a hard consistency, reflecting a higher stearic to oleic acid ratio, while in the cool highlands of Uganda, shea butter has a liquid consistency, indicating a high oleic to stearic acid ratio (Maranz et al., 2004). On the other hand, these differences in chemical composition have also been attributed to inherent genetic differences between subspecies *paradoxa* and *nilotica* (Allal et al., 2013). While phylogenetic diversity in *Vitellaria* is reported to vary along a longitudinal axis parallel to the equator (Fontaine et al., 2004), there is a strong latitudinal climate gradient occurring within the West African subspecies *paradoxa* populations (Maranz 2009). There are indications of climate-related differences in shea chemical composition within trees on the same sub-species. One example is the elevated oleic acid content of highland subspecies *paradoxa* populations in Western Cameroon and the western slopes of the Fouta Djalon in Guinea. Within the hot West African lowlands, climate gradients in fatty acid composition are more difficult to ascertain and are either weak (Maranz et al., 2004) or absent altogether (Allal et al., 2013).

The production of commercially secondary compounds such as certain triterpene alcohols also appears to be climate-driven within West Africa (Akihisa et al., 2010). An earlier study based on a different sample set also found a very high sterol content associated with the Dahomey Gap climate phenomenon (Di Vicenzo et al., 2005). Since the high sterol content of shea nuts is a key differentiator compared with competing oilseeds in some market applications, it is important to know the factors contributing to sterol synthesis. This also applies to other secondary compounds such as catechins and tocopherols. While the regional climate is a general indicator, another important factor is the immediate environment of the shea nut, especially post-harvest conditions (S. Maranz, pers. comm.). A critical point is that shea nuts remain biologically active even after dropping to the ground. Enzymatic processes within the seed during germination which will dictate viability, etc. could result in the synthesis of certain compounds and the breakdown of others. These processes are affected by heat, moisture and microbiological activity, but to an unknown extent, which can significantly affect the variation found in samples of fat composition studies. Thus, post-harvest seed chemistry and determining genetic factors are a critical area of future shea research.

Some domestication efforts have concentrated on germplasm collection, characterisation, evaluation and conservation. Shea germplasm collections were undertaken under the following four projects:

- Shea Tree Improvement Project funded by the Leverhulme Trust (CRIG-Ghana and Southampton Univ., UK), 1994-1998
- Improved management of agroforestry parklands in Sub-Saharan Africa, EC INCO research project, 1998-2003
- INNOVKAR: Innovative tools and techniques for sustainable use of the shea tree in Sudano-Sahelian zone, EC INCO Research project, 2006-2011

- Pro-Karité: Improving product quality and market access for shea butter originating from Sub-Saharan Africa, CFC/FIGOOF/23, 2004-2007

While these projects have generated a very rich set of studies on germplasm evaluation, chemical and diversity analyses, only a few provenance trials have been developed, thus limiting potential for elite germplasm deployment to farmers. A participatory selection trial with five provenances from Burkina Faso, Mali and Senegal was established in Gonsé, Burkina Faso to evaluate duration of the juvenile phase and large variability in annual fruit yields. A shea conservation plot has also been set up on the Samanko research station in Mali by ICRAF with a collection of 110 plus trees (clones) from Burkina Faso, Benin, Nigeria, Ghana, Cameroun, Niger, and Mali. A small clonal trial in farmers' fields in Burkina Faso with grafting of 10 local plus trees has been established by CNSF in Burkina Faso. New collections of germplasm with superior characteristics could be organized building on past collection data with a view to establish multilocational trials of multiple provenances to compare fruit, nut and fat content attributes of shea, and study genetic x environment interactions. Multiple sites for planted trials in each of the Sahelian, Sudanian and Guinean agroclimatic zones where shea occurs rather than only one site would make collections less vulnerable to stochastic and catastrophic events (Raebild et al., 2011). Shea germplasm at the extreme limits of its distribution area should be conserved for adaptation traits to drought in the dry northern part of the range and in the relatively humid areas in the south, especially if the species may shift in both directions with climate change. The same authors also note that there are no regional or even national plans for conservation of shea's genetic resources. Conservation efforts are not coordinated between countries, and are fragmented and depending on externally-funded projects.

Genetic erosion from clonal propagation is not a significant risk for *Vitellaria* due to its huge tree populations, vast distribution area and high levels of genetic variation. Thus regional collections of grafted accessions from across the shea region should be planned using existing grafting methods (Section 5.c) to allow for the rapid multiplication of superior trees in multiplication gardens. If they are replicated in several agro-climatically distinct locations such gardens can also allow the assessment of environmental influences on shea fruit/nut characteristics and the development of variety recommendations for different areas (Maranz et al., 2004).

f. An integrated approach to shea parkland regeneration and improvement

The importance of farmers actively protecting and managing natural shea regeneration in fallows and fields cannot be overemphasized. Parkland regeneration approaches should also be complemented with various tree propagation or tree management techniques presented above. Advances in shea domestication should be encouraged through necessary research and development investments that will lead to wider planting practices. However, genetic improvement should not be circumscribed to the planting of improved shea stands in the proximity of farmers' residence, but conceived as part of an integrated landscape-wide approach targeting relevant interventions in the various land use units of village landscapes (different fields, fallows, bush lands). A key responsibility of R&D practitioners is to promote the integration of the set of approaches and techniques for parkland regeneration, tree improvement and management presented in the above paragraphs and build capacity of farming communities to adopt them at significant scale. As a showcase of this approach, model parkland cases should be developed under local leadership (women groups, farmers, customary chiefs, local administration representatives, etc.) to demonstrate the value and benefits of intensified shea management (B. Bastide, pers. comm.). These model parklands would involve the implementation and upscaling of appropriate combinations of these techniques in a participatory manner.

E. Climate change: Impacts on shea and shea parklands as an adaptation measure

IPCC's 2014 fifth assessment report predicts that temperatures in Africa will rise faster than the global average increase during the 21st century (IPCC, 2014). Projected changes in mean annual temperature over most land areas of the continent range from less than 2°C to over 4°C in the first and second parts of the 21st century. The Sahel and tropical West Africa are identified as a hotspot of climate change (3-6°C for the end of the 21st century). Unprecedented climates are also projected to occur earliest (late 2030s to early 2040s) there due to the region's relatively small natural climate variability. Overall, precipitation projections are more uncertain and exhibit higher spatial and seasonal dependence than temperature projections. Many models indicate a wetter core rainfall season with a small delay to the rainy season by the end of the 21st century. However, according to regional climate models, rainfall for West Africa could be both wetter or drier, especially in regions of high or complex topography and near coasts.

In summary, the hydrological cycle over the shea range will intensify over coming decades (Diedhou, pers. comm.). Total annual rainfall will increase significantly. Experts, however, agree that rainfall seasonality will increase with much of this rainfall being in extreme and heavy rainfall events. The impact and utility of the rainfall will strongly depend on local land and soil cover conditions. The region is known for its high population density, intense and, in some places, permanent agricultural land use and degradation. Therefore paradoxically where land is currently degraded, such rainfall events are likely to be associated with lower than expected infiltration, intense runoff, and low aquifer recharge, thus reducing its utility to agriculture. Due to the deep root systems of trees, and functions in soil organic matter accumulation, a scattered tree cover provided by shea parklands will contribute to higher water infiltration and reduced surface water runoff compared to treeless areas.

The region will also experience levels of warming unknown in the past. An increase of 2.5°C in mean annual temperature is predicted for the Northern Sahelian region in mid-century and this increase will diminish going South towards the Equator. This will not only be reflected in changes in average temperatures, but also in minimum and maximum temperatures, which may be more significant for crop vulnerability to climate change. Minimal temperatures will increase in the Sahelo-Sudanian portion of the region, while there will be an increase of maximum temperatures in the Sudano-Guinean range of the area. Agronomically, considerations should not treat changes in temperature and rainfall independently, but together as it is the balance between both factors that plants are sensitive to, as reflected in evapotranspiration.

The modelled response of shea to increased temperature forecasts an increase in the number of climatically suitable areas for shea in the 21st century. Accordingly shea occurrence would expand within and outside its current range in the future (Platts et al., 2010). These authors report that the best environmental predictor of shea's current distribution proves to be the moisture index, defined as the ratio of annual rainfall and potential evapotranspiration. Peaking at moisture index values of 0.5-1.0, "shea is most likely to occur in relatively dry climates, but not too dry. It also occurs in wetter conditions, but not as often as it is out-competed". If rainfall increases in the northern part as predicted by some models, currently marginal areas that are drier than the moisture optimum (i.e., moisture index < 0.5) such as those at the northern limits of the shea range will become suitable for shea. Also, where shea is currently out-competed by other taxa due to wetter than optimal conditions (moisture index > 1.0), models predict increased climatic suitability in the 21st century" (Platts et al., 2010).

A good deal of uncertainty surrounds these predictions. Thus, these authors recommend that the health and establishment of shea trees be carefully monitored in relation to climate, particularly in marginal areas. Similarly it will be important to evaluate how climatic changes may affect the development of climate-dependent shea pests and diseases and their impact on shea population trends.

While the species seems to grow across a range of soil conditions, it is not found in depressions or frequently flooded locations. One may expect a negative impact on its occurrence in specific areas liable to a higher frequency of floods resulting from extreme rainfall events.

In turn, associating shea in farmed areas forming agroforestry parklands can help farmers in the shea belt adapt to impacts of climate change on staple and cash crop production. In similar agroforestry research work (coffee for instance), trees are shown to reduce temperature by 2-5 degrees for understorey plants under and around their crowns, reduce evaporation and increase organic carbon in these soils. Tree-soil-crop interactions are complex and vary according to tree and crop species, the distance between the cropping location and the tree as well as local agro-climatic conditions. Generally, crop production underneath shea trees is reduced compared to surrounding open areas, due to tree-crop competition for light, nutrients and water, light being the primary factor in cereal yield reduction (Bayala et al., 2012). Nevertheless, reduction of crop yields in the short term is compensated for by tree products (fruits, leaves, fuelwood, etc.) and other ecosystem services in the long term such as improved soil carbon and fertility.

Taking into account the above climate predictions and multiple benefits of shea (and other) tree-based systems in enhancing local community adaptation capacity to climate change, one should confidently recommend activities for the densification and restoration of degraded shea parklands through various available management practices (see section E.5).

Box 1. Summary of modelled impacts of climate change on shea

Climate change models predict the following impacts in West Africa:

1. Temperature
   - Increasing temperatures, especially in the Sahel (3-6°C for end of century)
   - Increased minimal temperatures in the northern part of the shea range and increased maximum temperatures in the Southern part of the shea range
2. Rainfall
   - Uncertain rainfall projections with high spatial variability
   - Wetter core rainfall season with a short delay by end of the 21st century
   - Increased rainfall in the central (Sudanian and Sudano-Sahelian) part of the region and more uncertain rainfall change when moving south.
   - Increased rainfall seasonality and extreme events. On degraded land, this will reduce usefulness of rainfall due to low soil infiltration, intense runoff, and low aquifer recharge. Shea parklands are better positioned to cope with extreme events than treeless areas.
3. Shea distribution with changing climate
   - Regional expansion of suitable areas for shea, both northward with increased rainfall in currently marginal areas and southward with increased temperatures.
   - Local displacement of shea in temporarily flooded areas
   - Shea trees offer a temperature buffer to intercrops in parklands. Shea agroforestry is thus an effective climate change adaptation measure.

F. Environmental impacts of shea processing

1. Resource use and carbon emissions of shea processing

Methods for the traditional preparation of shea butter vary depending on locations, and the process involves the use of significant quantities of water and fuelwood and generates waste. Shea butter production is also labour-intensive; in studies reviewed by Pouliot and Elias (2013) labour involved in butter processing from nuts ranges from 2.5 hours to as many as 10 hours per person per kilogram of butter (Terpend, 1982; Hyman, 1991; Hall et al., 1996; Crélerot, 1995; Faucon et al., 2001). However, a recent, detailed assessment based on bulk volume processing of 85-100kg sacks of shea nuts which appropriately reflect processing practices and multitasking in women's groups brings this value to 30-45 minutes per kg of shea butter (Lovett, 2014).

The need for heat occurs when roasting, smoking or boiling whole nuts to prevent germination (Figure 15), the heating of kernels by roasting or smoking prior to crushing and the boiling of the butter paste which is rinsed multiple times. Hyman (1991) estimated that the traditional production of a single kilogram of shea butter demands between 8.5 to 10 kilograms of fuelwood. In Eastern Burkina Faso, Noumi et al.'s detailed study (2013) showed that it took 7.9kg of wood to produce 1kg of butter (4.3kg for processing into kernels and 3.6kg for processing into butter) with traditional methods. This amounted to a total energy cost of 246 CFA F/kg, i.e. 31% of all costs for butter production.

Figure 15. Stirring of boiling shea nuts on traditional three-stone cookstove (source: Peter Lovett)

In Northern Ghana, Lovett (2014) reports that the preparation of kernels (collection, boiling, drying, de-husking and drying) is a set of tasks that women prefer undertaking on their own (or with trusted friends and family) as their labour in the process asserts their ownership of the nuts and it can only be rewarded through sale after full processing when de-husked, dried kernels acquire the value of a marketable commodity. In contrast, butter processing stages are often done collaboratively. The insistence to work individually on post-harvest processing puts cultural constraints on more efficient use of resources like labour, firewood and dryers. Similar processing practices likely apply to most of the shea region. Documentation of organizational arrangements in other areas would be useful, as they provide important aspects of the context for technology improvement.

Even though they are rarely investigated and documented in the literature, one can expect significant variations at the individual and community level in resource quantities used in kernel and butter processing practices. These may be linked to differences in technology used, governance and access rights to village-level fuelwood and water resources, availability of labour and means of transport, resource scarcity level, cultural habits, existence and membership in a local producer group and training experiences on improved technology efficiency and forest resource management, etc. These factors deserve to be better understood and taken into account in approaches to reduce emissions of shea butter production.

Firewood is becoming scarce especially in areas of high population pressure and its use contributes to deforestation and biodiversity loss. It can be a sustainably sourced carbon-neutral or positive biofuel (see section F.2). Women have to walk long distances to collect it or incur high costs to purchase it. The issue of smoke from cookstoves causing respiratory diseases is sometimes mentioned (Noumi et al., 2013). Yet shea nut boiling fires systematically take place in the open air (Lovett, 2014) and may only affect women or children in smaller settings of cooperatives promoted by NGOs where fire density can be high and result in air pollution. Overall, techniques to reduce energy consumption can have significant benefits, including saving women's key resource - time. Among those, methods that improve butter extraction also contribute to increasing butter quality and producers' income.

Figure 16. Semi-artisanal shea processing in the Nununa Foundation factory, Leo, Burkina Faso (source: Ademonla Djalal Arinloye)

Semi-mechanization at village level comprising a nut crusher, an improved roaster (Figure 16), a kneader or a hydraulic screw press reduces the use of resources. In Northern Ghana, traditional processing of kernels into 1kg butter required 9.04 litres of water and 3.25kg of wood, while semi-mechanization reduced water use by 24%, fuelwood by 11% and labour time by 58% (Jibreel et al., 2013). A slightly higher gain in labour time (70%) is mentioned by Wiemer and Altes (1989) in Pouliot and Elias (2013). Butter extraction efficiency (assuming that kernels contain 50% fat) is also improved (Addaquay, 2004). Noumi et al.'s (2013) cite an efficiency of 66.5% with traditional processing methods increasing to 80-85% with semi-mechanized processing.

In the first attempt to quantify the carbon footprint of a hand-crafted shea butter supply chain, the production of 1kg of refined hand-crafted shea butter formulated and packaged in a finished cosmetic product is estimated to provide a GHG emission value of 10.4 $kgCO_2eq$ (Glew and Lovett, 2014). Total emissions from the life cycle of shea butter are broken down by stages in Figure 17. Post-harvest processing (burning wood to heat water to boil the nuts) and traditional butter extraction (roasting nuts, heating water for kneading, boiling the fat) in the producing country are responsible for over 75% of the entire GHG supply chain emissions and are therefore clear priorities for emission reduction. Indeed, with a heat exchange yield of 4.3% and 9.1%, traditional three-stone cookstoves and roasters, as found in Eastern Burkina Faso lead to high heat wastage (Noumi et al., 2013).

However the Ojeda (2009) data used in the above calculation of GHG emissions by Glew and Lovett (2014) may overestimate resource use and specifically firewood use for boiling nuts in post-harvest processing. In a recent experimental study, emissions for the nut boiling stage amounted to 3.52 $kgCO_2$/kg butter in comparison to the formerly estimated 14.46 $kgCO_2$/kg butter or a 28% reduction of that particular processing step (Lovett, 2014). This brings the total GHG emission value to 6.1 kgCO2eq per kg of shea butter and the proportion of total emissions generated by the upstream in-country shea production to 58% only, while the proportion of final stages in Northern countries is 42% (Figure 18).

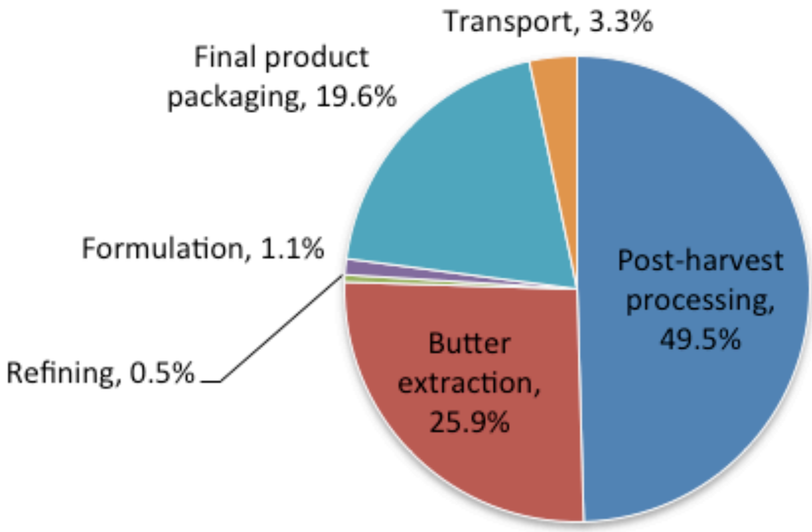

Figure 17. Shea butter supply chain GHG emissions (Glew and Lovett, 2014)

Due to the fact that information on products and profits was not readily available, economic allocation to distribute emissions could not be used in Glew and Lovett's study. Energy allocation is usually used in studies focusing on fuels. Therefore, mass was chosen as the basis for allocation. As a result, 64.5% of the emissions involved in de-husking are attributed to co-products of shea nut husks and kernel residue rather than shea butter itself. Likewise, 46.1% of the emissions resulting from raw butter extraction are allocated to the kernel residue. Allocation resulted in reducing the perceived emissions of shea butter by half and underscores the importance of using these co-products. Both husks and dried sludges are effective biofuels and can replace wood as they have a higher net heating value; 0.84kg of husks and 0.55kg of dried sludge can replace 1kg of wood, respectively (Noumi et al., 2013). Shea and other bioresidues are reported to be widely used throughout the processing of shea and efforts should be made to promote their commercialization for use by women shea processors (Lovett, 2014). Allocating emissions to shea husks and cake is therefore justified.

Communication of best practices and education of shea processors in producing countries will be key to reducing emissions. For instance, Lovett (2014) indicates that optimum kernel boiling times are between 15-40 minutes, using a fire as hot as possible to allow to rapidly bring as large loads of fresh shea nuts as possible to boiling temperature.

Simple alternative technical options including the use of shea processing co-products and improved cook stoves have been proposed to optimize energy consumption and reduce energy costs (Noumi et al., 2013). Their energy savings, economic performance and CO_2 emissions are highlighted in Table 3. The combination of scenarios 2 and 6 was associated with a reduction of energy cost from 31% to 6% of the total butter production cost and a gross margin almost double that of the baseline reference.

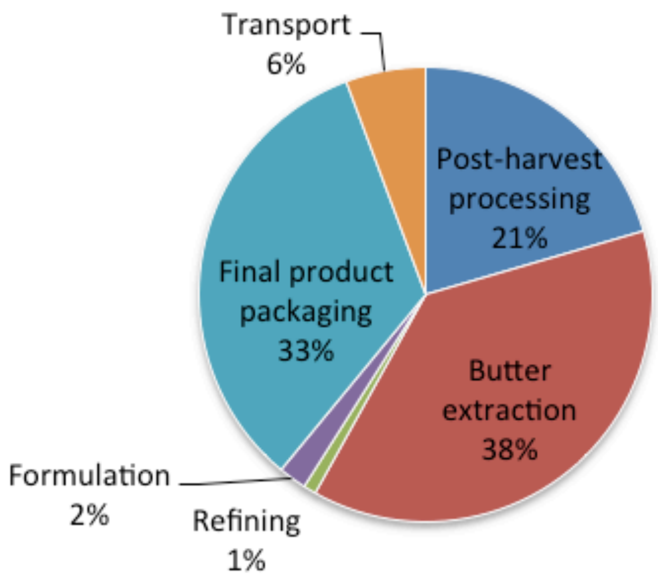

Figure 18. Shea butter supply chain GHG emissions as experimentally revised in Lovett (2014)

Glew and Lovett (2014) estimate that a 25% and 50% reduction in wood use with the adoption of efficient stoves would reduce emissions by 19% and 37%, respectively. Their study also suggests an estimated emission saving of 20% with mechanical extraction.

Much still needs to be done in adapting the design of improved cookstoves to the conditions of rural women and technical requirements of shea processing for optimal adoption. As pointed out earlier, the very high proportion of village women involved in shea nut collection (and post-harvest processing) (94% in Burkina Faso, Pouliot 2012) offers a large window for impact through technology improvement for boiling shea nuts compared to the far smaller number of women belonging to cooperative producer groups who may effectively take advantage of improved butter processing technology.

Table 3. Performance indicators of alternative energy techniques for shea butter production (Noumi et al., 2013)

Scenarios of technical options	% firewood savings re: traditional system	% increased gross margin/ kg butter	% decrease in $TeqCO_2$ re: current situation
Scenario 1 (gatherers): partial replacement of wood by nut shells	24	21	-0.03
Scenario 2 (gatherers): scenario 1 + improved banco cookstove	80	76	73
Scenario 3 (gatherers): shell dryer for nut drying	0	-0.1	0
Scenario 4 (processors): partial replacement of wood by churning sludges	26	25	-7
Scenario 5 (processors): scenario 4 + improved metal cookstove	17	30	10.3
Scenario 6 (processors): scenario 5 + gas roaster.	42	43	39

Apart from efforts to improve and assess energy efficiency performance, women requirements and increased benefits from improved stoves should be emphasized in applied research efforts toward their sustainable use. Local acceptability depends on several factors, including suitability to local practices (ergonomics, size, durability, technical performance), cost and efficiency increase to allow paying off the expenditure, local availability of the equipment and electricity when required, adequacy to the social function of collective shea work, among others. For instance, the common individual arrangement for post-harvest processing requires that improved technology used for boiling kernels be convenient and safe for use by a woman alone. The heavy 'improved' cookstoves need multiple persons to be shifted around, and considerable additional effort for cutting wood in smaller pieces which weighed further on women's time and capability (Lovett, 2014). Rainy season findings also demonstrate the mud-stoves collapse and clay-filled designs can get water-logged and become difficult to heat up.

There are several opportunities for the local adoption of the technical options (banco cookstove, metal cookstove, roaster) proposed by Noumi et al. (2013). Some of them are already promoted in extension campaigns in Burkina Faso and do not involve any major alteration in work organization. Equipment can be made locally or bought in the local market. However access to credit can be a limitation and affordability would require proper cost-benefit analyses.

Impacts of the introduction of mechanical extractors in the supply chain also need to be assessed. Processing units may not be located in shea producing areas and may involve enterprises or cooperatives with sufficient startup investment capital rather than producers themselves. The ability of women to take advantage of mechanization and labour-saving devices (without giving a large share of profit to male-operators) will depend on their business skills and organizational capacity. Impacts on income and livelihoods of local producers and changes would thus need to be assessed and changes in carbon emissions factored in (Glew and Lovett, 2014).

2. Carbon-neutral fuel sourcing for shea processing

The slow growing nature of the *Vitellaria paradoxa* tree gives it a dense wood and a source of slow and hot-burning fuelwood and charcoal which is preferred by local communities over other species, even though it does spit sparks especially when made into charcoal. Shea is a component of natural vegetation and in places like Northern Ghana its wood is widely used in both post-harvest kernel and butter processing in terms of frequency as well as average firewood weight (Lovett, 2014; Hansen et al., 2012). In Mali, Nouvellet et al. (2006) also report that pruned shea branches and felled trees make up a large part of fuelwood for villages and large cities, despite national legal prohibitions of tree harvesting. Most fuelwood is harvested in the forest domain with a protected status, though a large part also originates from parklands.

Farmer selection and management practices emphasized throughout this report (in particular section D.1) have made shea (and other tree species) abundant in parkland landscapes because of its multiple uses (food, fuelwood, fodder, construction, etc.). Shea is the most common tree species in these parklands, so naturally it is also the most readily available as dead wood and for cutting. Farmers' resource management logic involves selecting and nurturing shea trees with desired traits and the felling and removing of dead, old or unproductive trees to be used as fuelwood or for construction. In a sound management system, as applied for instance to apple orchards or poplar biofuel plantations in northern countries, unproductive or over mature old trees are removed and replaced by young ones. Instead of being planted as would be the case for new young apple or poplar trees in northern plantations, shea trees are selected by farmers from natural regeneration at the outset of a fallow period and protected in the subsequent cultivation cycle(s). Therefore it is not surprising that shea makes up a significant part of firewood supplies, including those used for shea processing.

The misperception that harvesting of indigenous trees for firewood is 'a bad thing' needs to be addressed (Lovett, 2014). It is not uncommon that development actors perceive that 'natural' woodlands are being degraded as a result of excessive fuelwood harvesting by local populations (Hansen et al., 2012). They have misgivings about farmers' ability to manage tree resources adequately and are concerned that local practices indiscriminately lead to permanent desertification, land degradation and the loss of biodiversity and other ecosystem services. As mentioned in section D.1., in the great majority of cases such lands perceived as 'natural' woodlands are not virgin dry forests but agroforestry landscape systems that have been man-managed for centuries and where economic species have been favoured through selection for human use.

The above views recall well-known but criticized narratives of resource depletion and environmental crisis in West Africa that contradicted the field realities and initiatives of rural communities to enrich local landscapes and misread the history of forest change. For instance, by comparing aerial and satellite imagery from 1952 and 1992, Fairhead and Leach (1996) showed that in the Kissidougou forest savannah transition area in Guinea in which forest islands were assumed by the forest research and policy community to be relicts of a more extensive forest long degraded by local people, the area of forest and secondary forest thicket vegetation has remained either remarkably stable or had expanded in surface area, sometimes considerably (50-500%). Many forest islands around villages were in fact established by local populations, and the open savannah had also been enriched with more woody species. Similarly, the environmental discourse of development organizations in Côte d'Ivoire ran against the scientifically documented increase of tree density in savannahs over a 30-year course which was also observed by local farmers (Bassett and Koli Bi, 2000). While their study in Northern Ghana does not include longitudinal vegetation assessments, Hansen et al. (2012) found that farmers' decisions and practices about indigenous tree selection, protection and management which are informed by extensive knowledge about tree species and their uses, as well as observed parkland tree densities did not warrant the pessimism of development organizations.

Furthermore, available studies on regeneration do not support predictions of ecological decline (Ribot, 1999) and there is evidence that Sahelian forest vegetation coppices and regenerates vigorously after woodcutting and can sustain rotations of 4 to 12 years (Ribot, 1995). Because carbon is sequestered during tree regrowth cycles, the wood-cutting and burning process does not contribute to increased GHG emissions. Therefore managed stands of indigenous species can potentially be a sustainable source of biofuel.

This is not to say that some areas do not experience severe degradation as a result of wood harvesting. Forest commons found between villages are often characterized by poorly articulated tenure regimes. Unclear boundaries, overlapping claims by local communities and a lack of inter-village institutional mechanisms to coordinate resource use and manage conflict may result in suboptimal woodland management. This is exacerbated when these woodlands are encroached by organized, often urban-based groups of commercial firewood collectors which have gained access to the resource through the support of modern forest legislation (Ribot, 1995). Another source of great concern is the stumping of parkland trees in large-scale land development projects for intensive food and biomass crops which have multiplied in the West African Sahel in recent years.

The current constraint to carbon-neutral fuelwood production is the lack of knowledge about how production is managed and frameworks regulating where firewood which is sold to shea producers, is coming from. Lovett (2014) provides a relevant agenda to address the development of carbon-neutral fuelwood supply systems. "It is recommended that sustainably managed firewood supplies are identified, developed and verified through traceable and certifiable systems. Provided no land use conversion occurs, appropriate sources can then be reclassified as sustainable and carbon-neutral biofuels can be sold at premium prices as the firewood of choice for other certified shea butter production systems, e.g. organic and fairly-traded. Other non-sustainable firewood production can then be red-flagged, technical and institutional support provided and regulatory authorities involved to control use until sustainability has been achieved".

Even though parklands are dominated by one or a few tree species, they also contain a wide range of other woody species depending on rainfall, state of degradation, local needs and knowledge about trees. Numbers vary from 43 to 110 woody species according to studies (Gijsbers et al., 1994; Boffa, 1995; Bayala et al., 2011; Kindt et al., 2008). Farmer management of parklands has thus contributed to the sustainable use and conservation of parkland biodiversity over time. Discouraging firewood harvesting and other uses in parklands will inevitably lead to a notable loss of diversity in these shea production systems. In contrast, sustainable use of the range of indigenous trees for firewood and other uses (fruits, medicines, roofing/construction material, etc.) is a sure and proven avenue to conserve biodiversity in situ.

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