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A holistic approach to sustainable agriculture: trees, science and global society

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1 Introduction

How many people understand the connection between trees, science and global society? Sadly, the answer is probably 'very few', yet arguably the future of our planet probably depends on getting the connections and the relationships between them correct. Trees, in fact, are a greatly underutilized resource that play crucial environmental roles of great importance to the sustainability and the productivity of global ecosystems. Trees, especially from the tropics/subtropics, are also the source of numerous useful products, which again have been overlooked by science and society and could be part of a hugely diversified set of new industries of great importance to the global economy. Both these roles are poorly understood by international and national policy makers, with the role of trees in the productivity of agriculture being grossly misunderstood and overlooked, as will be explained later. Indeed, the cultural and traditional use of a wide range of tree products by local people has been poorly recognized right back to colonial times (Maathai, 2009), despite correspondence by early missionaries in Africa to colonial administrators (e.g. Harry Leakey Archive in the Bodleian Library, Oxford).

An obvious conclusion from these statements is that there is 'work to be done' to harness these overlooked benefits for both humankind and the planet. That of course leads us to the need for scientific investigations about how to

http://dx.doi.org/10.19103/AS.2018.0041.25

Chapter taken from: Mosquera-Losada, M. R. and Prabhu, R. (eds.), *Agroforestry for sustainable agriculture*, Burleigh Dodds Science Publishing, Cambridge, UK, 2019, (ISBN: 978 1 78676 220 7; www.bdspublishing.com)

best capture these benefits so that global society can take advantage of the overlooked opportunities and use them to support the increasingly demanding needs of a growing human population and improve the equity in the wealth derived from them. Greater equity might even lead to much greater harmony between the peoples of our divided and conflict-ridden world of extremely rich and extremely poor. This chapter reviews recent progress in this direction through agroforestry and looks at the opportunities for further progress.

2 Trees: an underutilized resource for agriculture

The definition of a tree is far from easy, but there are said to be 60 065 tree species in the world (Beech et al., 2017). The difficulties in definition are due to the grey line between what is a 'tree' and a 'shrub'; the importance of 'woodiness', and the importance of the distinction between monocotyledons and dicotyledons. Typically, agroforestry involves trees for timber, wood, fruits and nuts, medicines and a very wide range of other useful products and environmental/ecological services. In this chapter the word 'tree' is used to refer to trees and shrubs, all woody perennials, palms and bamboo, in accordance with the Corporate Strategy 2017–26 of the World Agroforestry Centre (https://www.worldagroforestry.org/sites/default/files/users/admin/Strategy%20Report_2017.pdf).

Of the approximately 250 000 plant species in the world about 20 000 (4%) have edible products, many of which are trees, yet only about 0.3% of these edible plants are cultivated in agriculture (Leakey and Tomich, 1999), with just 12 plant species contributing about 75% of our food (FAO, 1999). Despite this apparently low use of edible species, there is good evidence from ethnobotany of the much wider use of plant species by indigenous peoples around the world for food and many other day-to-day uses (Cunningham, 2001). It was the discrepancy between the agricultural and the ethnobotanical use of plants that gave rise to the term 'Cinderella species' to describe those species which could be formally domesticated to 'make the land more productive and . . . contribute to domestic, regional and international trade' (Leakey and Newton, 1994). To get 'Cinderella' to this 'Ball' it was realized that there were social, political, economic and biological issues to be resolved.

Over the last 25 years much progress has been made to bring underutilized indigenous species, especially fruits and nuts, into formal domestication (Leakey et al., 2012). This process builds on ethnobotany and the traditional knowledge of local people (Franzel et al., 1996; Cunningham, 2001). Key factors driving this process have been (1) the upsurge of biological and social research on the importance of these little-known Cinderella species to local people (Schreckenberg et al., 2002; Leakey, 2012) and (2) the development and implementation of a participatory process of decentralized domestication which puts the communities in the driving seat, as well as making them the recipients of the economic and social benefits (Leakey et al., 2003; Leakey, 2014a). The success of this participatory process has led to the recognition of these farmer-developed horticultural cultivars as 'socially modified organisms' (Leakey, 2017a) with the capacity to address the very serious 'cycle of land degradation and social deprivation' that underlies the environmental, social and economic constraints to food production and rural development in the tropics and subtropics (Leakey, 2013).

3 Trees: prerequisites for the use of underutilized indigenous species

The agroforestry research underpinning the domestication of these little-known tree species has been multidisciplinary.

3.1 Vegetative propagation

Development of vegetative propagation techniques is essential so that the phenotypic genetic characteristics of elite trees can be captured as horticultural cultivars (Leakey, 2014b). Until the 1970s the vegetative propagation of many trees was severely constrained by a lack of fundamental knowledge of the processes determining success; despite centuries of successful propagation by 'green-fingered' horticulturalists. Since then, more rigorous studies have evaluated the importance of pre-severance and post-severance factors culminating in some widely applicable general principles (Leakey, 2014b). It has emerged that, through its impact on the morphology and physiology of subsequently severed cuttings, rigorous pre-severance management of stockplants is fundamental to the achievement of a robust and productive programme of propagation. In parallel with this, the development of low-technology propagation facilities appropriate for use in remote rural areas without piped water or electricity have allowed the establishment of simple village-level tree nurseries at very low cost (Leakey, 1996, 2014b).

3.2 Characterization of tree-to-tree variation

This clonal approach to domestication has used simple techniques to determine the extent of tree-to-tree variation in characteristics that are important for the quality and marketability of the tree products. Such studies have now been done for many tropical tree species entering domestication programmes (e.g. *Canarium indicum*, Leakey et al., 2008) and included traits such as fruit/nut morphology, nutritional/medicinal properties, chemical composition of oils/fats, essential oils and so on. The results of these studies have then led to the formulation of 'ideotypes' to meet the needs of consumers and new industries (Leakey and Page, 2006). Importantly, around 85% of this tree-to-tree variation has been found to occur at different sites (de Smedt et al., 2011; Pauku et al., 2010). This indicates that the decentralized approach to tree domestication has the potential to achieve very significant improvements in the selected traits, as well as lowering the risk of seriously narrowing the genetic diversity of these species (Leakey, 2012).

3.3 Technical support

Practical success depends on the provision of technical support for participatory domestication programmes. This has been achieved by the creation of community-based Rural Resource Centres (Degrande et al., 2015) in partnership with community-based organizations (CBOs) or non-governmental organizations (NGOs). These provide the hands-on training, information and knowledge that allows farmers to develop small-scale tree nurseries, set up simple vegetative propagation facilities, initiate elite tree selection, manage multiplication gardens and establish agroforestry systems on their own farms. Among these skills is the well-known agroforestry practice of using leguminous trees and shrubs in agroforestry to fix atmospheric nitrogen in their root nodules and so to improve soil fertility (Sileshi et al., 2014). Putting these newfound skills together, farmers are empowered to address the big constraints that have been limiting the productivity of their farming systems for decades, namely soil infertility and poverty, in association with hunger and malnutrition (Leakey, 2013).

In addition to these practical field skills, the training provided by Rural Resource Centres also provides knowledge in community management, financial management, marketing and trade, use of microfinance, local infrastructure developments and so on. In parallel with this capacity-building programme, research on the development process was initiated in order to enhance and upscale the concepts and initiatives, with a focus on farmer livelihood strategies (Schreckenberg et al., 2006; Degrande et al., 2006); community capacity-building processes (Degrande et al., 2012; Takoutsing et al., 2014; Franzel et al., 2015); farmers' rights (Gyau et al., 2014); product uses and markets (Cosyns et al., 2011, 2013; Facheux et al., 2006, 2007); adoption of innovation (Mbosso et al., 2015); incentives to plant and national law (Foundjem-Tita et al., 2013); rural development issues (Foundjem-Tita et al., 2011, 2012; Gyau et al., 2012), processing and value chains (Degrande et al., 2014); and impact (Facheux et al., 2012) have been investigated. These advances in the social sciences of community engagement have led to Rural Resource Centres now being adopted in other African countries.

Once equipped with the technical knowledge and engaged in a self-help process with obvious livelihood benefits, these farmers put it into practice in their own farms in whatever way best meets their own needs. The knowledge acquired in Rural Resource Centres provide these farmers with the skills to implement generic steps towards more productive and sustainable agriculture and better lives, namely (Leakey, 2013):

- the use of leguminous trees and shrubs to restore soil nitrogen,
- the domestication of locally important indigenous trees and
- commercialization of tree nurseries and tree products.

Together with local processing and value-adding, the last of these steps creates urban as well as rural employment (Lombard and Leakey, 2010; Leakey and van Damme, 2014).

These steps can be applied in sequence or simultaneously (Leakey, 2012, 2013) to address the key problem facing tropical/subtropical agriculture – the yield gap between the potential yield of modern staple crop varieties and the actual yield achieved by farmers. Yield gaps are the outcome of the 'cycle of land degradation and social deprivation' caused by the inaccessibility to modern technologies faced by ultra-poor subsistence farmers with only 2–3 ha of degrading land. So, with the training they have received, farmers can apply the three agroforestry steps mentioned above, improve their crop yields, produce more nutritious food and become wealthier (Asaah et al., 2011a; Leakey, 2012, 2013, 2017a). The new culturally important agroforestry crops domesticated by these farming communities underpin this self-help approach to self-sufficiency and a better lifestyle and have been described as the 'socially modified organisms/crops' (Leakey, 2017b).

The above approach to agroforestry also has very important agroecological and environmental benefits resulting from the diversification of the farming system with both nitrogen-fixing trees and the socially modified crops. The former ameliorate soil nitrogen deficiencies, while the latter produce marketable products. Both these sets of long-lived woody perennials can therefore be considered as the ecological 'heart' of agricultural and natural ecosystems (Leakey, 2014c). This role is fundamental to agroforestry which has been defined as a means to creating an agroecological succession, akin to that in natural ecosystems (Leakey, 1996, 2014c). A healthy, functioning ecosystem is important for the maintenance of the nutrient, water and carbon cycles: the stability of the ecosystem through the completion of food chains and life cycles. These roles together regulate the natural balance between different organisms and reduce the risk of weed, pest and disease outbreaks (Leakey, 2017c). They are also important for pollination and seed dispersal which maintain the reproductive health and longevity of the component organisms. When these ecological functions are destroyed by deforestation and the cultivation of crop monocultures, conventional modern agriculture depends on artificial fertilizers and pesticides to control pest, disease and weed outbreaks: inputs which are inaccessible to poor subsistence farmers. Additional outcomes from mainstream agriculture are the breakdown of the hydrological and carbon cycles, which lead to increased run-off to waterways, reduced recharge of groundwater, reduced advection of moisture to the atmosphere and importantly to the emission of greenhouse gas which promote climate change.

From all the above, and indeed the contents of this and many other books (e.g. Nair and Garrity, 2012; Atangana et al., 2014; Leakey, 2017a), as well as thousands of research publications, it is clear that trees in agroforestry systems are fundamental to sustainable agriculture, especially in the tropics and subtropics. This then leads our discussion in two important directions:

- what research is needed to further improve these approaches to agroforestry?
- how can the social, political and economic constraints that hinder the implementation of more sustainable agroforestry practices be resolved?

These issues are discussed in more detail below.

4 Science: priorities in agroforestry research

Agroforestry is a relatively new science, with early advocates recognizing the need for trees in sloping field systems to minimize soil erosion (Leakey, 1949). Institutionally, agroforestry was established in the 1970s with the creation of the International Council for Research in Agroforestry in Nairobi, Kenya. From the outset, as the approach to problem solving, it used participatory techniques to determine the needs and priorities of local farmers – 'Diagnosis & Design' (Raintree, 1987). In more recent years, a participatory approach has been used to ensure that tree domestication is effectively adopted by local farmers (Leakey, 2014a). This contrasts with much top-down modern agricultural research in which scientists select an interesting research project that seems to fit a topical problem.

A review of the science agenda for agroforestry in humid West Africa at the end of the twentieth century identified tree domestication and its linkages with commerce as priority research issues; together with the integration of domesticates within multi-strata agroforests for both their agroecological benefits and income generation (Leakey, 1998). More recently, advances in agroecology have indicated how agroforestry provides ecological niches above- and below-ground for colonization by a wide array of organisms that promote wildlife conservation in addition to ecological functions such as nutrient cycling, soil health and groundwater management (Garbach et al., 2014; Lavelle et al., 2014; Leakey, 1996, 2014c, 2017c; Hobley et al., 2017).

However, scientific knowledge and understanding of the numerous interacting factors is poor and is a challenging frontier for much more detailed research (Leakey, 2014c).

As large, long-lived, perennials, trees have adapted to the many environments found in both pioneer and mature ecosystems. There is therefore also a need for much better understanding of tree biology, especially the physiology of phase change during maturation and the genetics of adaptation to a very wide range of climates and soils. Tree biology and the enhancement of their role in agroecology thus represent the ultimate challenges for scientists wishing to develop new tree crops (Leakey et al., 2012; Leakey, 2014c).

4.1 Advances in vegetative propagation

The successful rooting of stem cuttings has been built on the development of robust and appropriate vegetative propagation techniques using simple, low-technology propagators (Leakey et al., 1990). These were developed for use by rural communities living in remote villages without electricity and piped water using practical protocols based on sound principles. Special importance has been focused on an understanding of the numerous pre- and post-severance factors determining the successful vegetative propagation by leafy stem cuttings (Leakey, 2004, 2014b), such as the differences in leaf size and internode length, and the effects of nutrition, irradiance and light quality regimes on different stockplant shoots (Leakey, 2014b). Community-level training in these techniques has allowed many species to be propagated vegetatively as cultivars in village nurseries (Tchoundjeu et al., 2002; Ngo Mpeck et al., 2003) from selected individual elite trees identified by the farmers themselves (Mbile et al., 2004).

To capture the mature phase of the tree crown and so achieve early fruiting (Fig. 1), it is easiest to use grafting or air layering techniques as the rooting ability of cuttings is often said to be negatively affected by the development of sexual maturity. The rooting ability of mature cuttings is a topic which in my view suffers from flawed understanding of tree development. Consequently, it is a topic where our knowledge of how to manipulate the rooting ability of shoots from within the crown of mature trees needs to be greatly improved (Dick and Leakey, 2006). This is perhaps the greatest challenge for plant physiologists engaged in tree domestication.

Despite our improved knowledge of the rooting process, some trees remain a domestication challenge – such as *Allanblackia* species. In this case, success is hindered by slow rooting and the formation of very few roots (Tsobeng et al., 2016). Furthermore, the shoots of rooted cuttings of these species tend to grow plagiotropically – that is not vertically – as these species are characterized by weeping branches. This is an epigenetic trait associated with

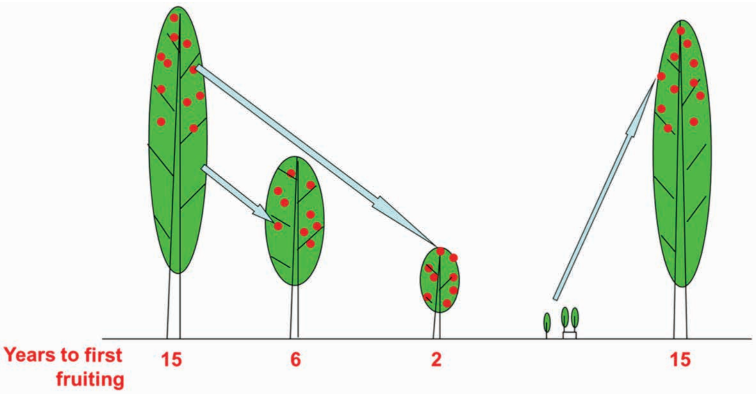

Figure 1 Effects of vegetatively propagating shoots from the adolescent, mature or juvenile parts of a tree on the time to fruiting (After: Leakey, 2017a).

topophysis, nevertheless ways can sometimes be found to release accessory buds capable of orthotropic, or vertical, growth (Leakey, 1990). Plagiotropism is often associated with cuttings from the sexually mature crown of trees – that is those with the capacity to immediately flower and produce fruits. This is a trait of great importance when domesticating fruit and nut trees typically captured by the techniques of air layering or marcotting, and grafting (Mialoundama et al., 2002; Tchoundjeu et al., 2010; Ofori et al., 2015; Asaah et al., 2011b). However, there is a need for much greater understanding of the numerous factors determining propagation success by these techniques. Associated with these research topics is the need for rootstock selection to control tree growth (dwarfing) and fruit yield.

4.2 Improving the understanding of tree biology

As the discussion of research priorities in agroforestry and vegetative propagation suggests, there is an urgent need for a better understanding of reproductive and other aspects of tree biology. These issues include:

- Understanding and managing processes of sexual maturation
- Understanding and managing physiological variation
- Controlling seasonality in production

Addressing these challenges will be critical in ensuring commercial production of a consistent product suited to market needs.

Earlier we saw that the physiological processes of sexual maturation in trees is a research topic important for vegetative propagation, but of course many aspects of reproductive biology are also important in tree breeding and seed production. Among these are questions about the tree-to-tree variation in sexuality. Trees are typically reported to be either monoecious or dioecious but actually there may in fact be the full range of dioecious sexuality from 100% male to 100% female, and everything in between, as monoecious/hermaphrodite species can be seen to vary in their male:female ratios, affecting pollination success, which obviously requires both sexes. When unproductive male fruit trees are cut down, as has been reported in *Sclerocarya birrea*, poor pollination seems to result in fewer kernels per nut (Leakey et al., 2005b), but it is not known how many male trees are needed to effectively fertilize a predominantly female stand. This may also be manipulated by the appropriate location of beehives to boost pollination success.

Time to first flowering is one of the biggest constraints to tree breeding, affecting generation time. Thus, controlled breeding would be eased if ways can be found to induce the capacity to flower precociously and produce viable seeds in sexually juvenile shoots, like seedlings. Some success has been achieved in the manipulation of the physiology of sexual maturation in trees (Longman, 1978; Leakey et al., 1981), but it is still very poorly understood, making it difficult to induce and manipulate flowering for the purposes of rapid tree breeding.

Another related issue is the physiological variation associated with developing a mature tree. In timber tree species correlative inhibition is thought to regulate the proleptic and sylleptic branching processes that control tree form and branching characteristics (Leakey, 1986), and so determine log volume and stem form (Ladipo et al., 1991). Research has, however, indicated that even within a single tree species the tree-to-tree variation in these processes is approximately 10-fold. Thus, in *Triplochiton scleroxylon* for example, the development of cultivars with very strong correlative inhibition would be appropriate for lumber, while those at the other extreme would be best for edible leaf production from managed hedges.

Physiological processes like branching and stem elongation, leaf thickness, photosynthesis and so on are strongly affected by the environment (especially nutrients, light quality, irradiance, temperature, day length etc.) affecting growth and the partitioning of dry matter affecting harvest index (Ladipo et al., 1992). However, there has been very little research to optimize the capture of physiological and intraspecific genetic variation, and their interactions.

Finally, there is much to learn about the ripening of fruits. This is important for the marketing of fruits which is often severely constrained by the ‘shelf life’ of the products. While techniques can be developed to preserve the products, there is also the opportunity to select cultivars which are inherently ‘in season’ at times outside the typical natural range. For example, the cultivar ‘Noël’ of *Dacryodes edulis* fruits in December when the main season is May–September (Leakey et al., 2003). Controlled pollination may be needed to breed for trees fruiting throughout the year, and hence develop them as cultivars.

4.3 Capturing genetic variation

A horticultural approach to tree domestication based on the vegetative propagation of elite trees raises the question of how to identify the candidate trees? This in turn raises questions about how much intraspecific variation is available, and what is the structure of this variation in wild populations of different species from different environments?

Three approaches have been engaged to seek answers to these questions. The first and easiest is to allow the farmers to use their local knowledge about the size of the fruits, their flavour or some other attributes, like oiliness – and how this affects the price paid in the local marketplace. Secondly, simple measurements of key traits can quantify tree-to-tree intraspecific variability (Leakey et al., 2000). This data can be used to calibrate local knowledge, and to assess the magnitude of the variation in the local population – for example in 100 trees of Marula (Leakey et al., 2005a,b), Canarium (Leakey et al., 2008), Allanblackia (Atangana et al., 2011) and Sandalwood (Page et al., 2010). This approach can also be used to assess more complex traits, such as nutrient content, fatty acid profiles, food thickening properties, wood quality and so on in a laboratory (Leakey et al., 2012). Measuring the extent of this intraspecific diversity allows the identification of multi-trait 'ideotypes' meeting different combinations of market-oriented traits (Leakey and Page, 2006). Thirdly, DNA analysis can examine genetic diversity with regard to the relatedness of different trees and different populations and the identification of genetic markers for selection, or to determine priorities for genetic conservation (Lowe et al., 2000; Jamnadass et al., 2009; Muchugi et al., 2008; Pauku et al., 2010).

Some of the above qualitative traits will become increasingly important as the use of ideotypes expands to meet more sophisticated opportunities, such as the independent traits of viscosity and the drawability of polysaccharides determining the food thickening properties of *Irvingia gabonensis* (Leakey et al., 2005c). In the future there will probably be a greater need to capture desirable traits, such as biochemical profiles affecting nutrition and anti-nutrients. It is important in this connection to recognize that due to the considerable tree-to-tree variation in these traits the species average is a 'very blunt instrument' when trying to select trees to address the problem of malnutrition. The same is true when quantifying sensory traits (taste and smell) such as astringency, sweetness, acidity and so on which can be linked to molecular genetic profiles to aid tree breeding.

In the future, molecular approaches to studies of variation will probably become applicable to the assessment of epigenetic variation within an individual organism – such things as plagiotropism, sexuality and fecundity, probably with extensive tree-to-tree variation.

The importance of tree-to-tree variation raises the broader issue of conserving genetic diversity. Conservationists are often concerned about the potential (and frequently real) loss of genetic diversity associated with domestication. No quantitative study has been made of the impact of decentralized participatory domestication of the indigenous trees being cultivated in agroforestry systems. However, a domestication strategy has been published (Leakey and Akinnifesi, 2008) which emphasizes the need for long-term availability of genetically superior plants – seed sources and elite horticultural cultivars. Importantly, studies have identified very high proportion of the intraspecific tree-to-tree variation found in different populations (de Smeldt et al., 2011; Leakey et al., 2005a,b) and that the trees with superior traits are typically unrelated (Pauku et al., 2010). Thus, it seems that decentralized domestication should minimize the loss of genetic diversity. Nevertheless, it is important to ensure that communities engaged in domestication are aware of the risks and the need to maximize genetic diversity within their area.

4.4 Testing cultivars to meet market needs

A further set of issues relate to how best to exploit the commercial potential of currently underutilized tree species. As has been discussed, despite the progress in tree domestication described above, much remains to be done to underpin the science, and to test that the cultivars are delivering the expected benefits to remote communities. Many farmers in Cameroon have already created elite clonal cultivars of *Dacryodes edulis, Irvingia gabonensis, Ricinodendron heudelotii, Garcinia kola, Cola nitida, Allanblackia* spp. and so on, but none of these clones have been evaluated in formal field trials to determine if they meet either the selection criteria, or the ideotypes required by urban markets or processing industries. These tests are also required to provide the information needed to register the clones for the protection of intellectual property rights (Lombard and Leakey, 2010). A prerequisite of these evaluations, and subsequent marketing, is the rigorous identification of the clonal material by a name or number and the maintenance of information on its geographic origin and ownership.

The field testing of cultivars is critical to building on the earlier success of ICRAF's work in Cameroon and the intellectual, physical and social capital already invested in tree domestication. It is also essential for the expansion of the technology into a new generation of genetic traits of great importance for the marketability of AFTPs.

4.5 Post-harvest processing

Almost no work has been done to improve the shelf-life of perishable African fruits by developing post-harvest product processing and value addition by drying, bottling or canning. This is important as markets demand greater uniformity, quality and reliability of supply to make further progress in the value chain and as the legislation on food safety becomes stricter. It is for these reasons that the processes of domestication and commercialization should run in parallel (Leakey and van Damme, 2014). This processing also expands the nutritional benefits of these traditional foods to consumers throughout the year and allows their transportation to more remote markets. Year-round production would also benefit producers because of the higher prices they could charge for making produce available out of season. Opportunities also exist for more complex post-harvest processing to improve market appeal of fruit pulp, kernels or leaves. Fermentation, for example, has been a critical factor in the commercial success of coffee, tea and cocoa. Research on these possibilities should take advantage of multi-trait ideotypes capturing rare trait combinations present in individual trees within both wild or bred populations.

To ensure many of the above initiatives are implemented effectively, there is the hope that 'big business' will see the benefits to develop partnerships with local communities engaged in domestication and cottage industries in tropical and subtropical countries so that communities can benefit from the increased economic returns derived from value-addition (Lombard and Leakey, 2010). These companies will in turn derive benefits from a wider customer base and from new food and non-food products derived from appropriately protected traditional and cultural knowledge. There is growing recognition of the importance of wild foods in the diet, nutrition and health of the peoples of tropical and subtropical countries (Schnorr et al., 2014). Thus, unlike conventional staple foods, it seems likely that the decentralized domestication of a wide range of indigenous food species could have important implications for the dietary health of global consumers, and perhaps have positive impacts in current campaigns against obesity and food allergies.

4.6 Capacity building in applied science

Local communities need the resources and infrastructure to develop new crops and build on these market opportunities. As knowledge progresses from the ethnobotany of wild species to that of socially modified crops (Leakey, 2017b), there will be a need to greatly enhance the capacity of local communities to engage in tree domestication, agroforestry planting and management, marketing and use of microfinance, infrastructure development, community finance management and so on. Much of this has already been initiated by the development of Rural Resource Centres (Degrande et al., 2015). However, as these Centres spread, new training programmes and skills will be needed to ensure that the production of AFTPs effectively promotes income generation, rural and urban livelihoods, as well as the formation ecological niches in support of agroecosystem functions (Ong and Leakey, 1999). This should include compliance with government legislation on trade and product processing, intellectual property rights and genetic conservation (Leakey, 2017a; Leakey and Prabhu, 2017).

5 Global society: meeting the need for sustainable intensification

The UN Millennium and Sustainable Development Goals have set out targets for international development, while numerous international reports (MEA, GEO, IAASTD etc.) have called for more sustainable farming systems in the tropics and subtropics. However, a practical, appropriate and effective solution to food and nutritional insecurity has been elusive for about 100 years. Conventional thinking and policy has been based on the concept that what works in temperate latitudes must work in the tropics and subtropics. Unfortunately, this fails to recognize that the biophysical, social and economic conditions in industrialized countries dominant in temperate latitudes differ dramatically from the developing countries of the tropics and subtropics, especially in Africa. The result of this has been a two-tier and dysfunctional world exceeding its 'planetary boundaries' threatened by climate change (Campbell et al., 2017) and divided between the rich and the extremely poor (Fig. 2).

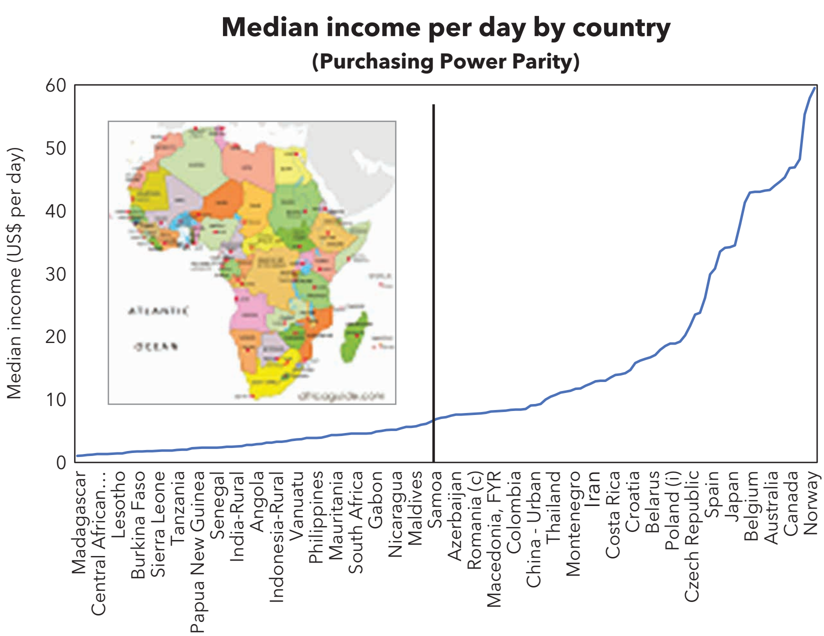

Figure 2 The median income per day (adjusted for purchasing power parity) of countries across the world in US$ per day (Diofasi and Birdsall, 2016). Note: All African countries fall below the median of these medians.

There are two critical issues here: firstly, hundreds of millions of households living on the brink of the cash economy depend on small farms (1–5 ha) to meet all their daily needs without any social support systems. Secondly, these people are unable to purchase the essential technical inputs necessary to cultivate monocultures of staple food crops. This results in deforestation and a downward spiral of declining soil fertility with the loss of agroecological functions and so to declining crop yields, hunger and malnutrition. This land degradation also traps these deprived rural households in poverty and social inequity (Leakey, 2012).

Part of this scenario is the view, held by many from industrialized countries, that trees are a hindrance to cultivation and should be removed. This view fails to recognize that trees are crucial environmentally as the keystone of mature ecosystems, and socially because many are the source of culturally important food and non-food products (www.mongabay.com). This leads to serious negative trade-offs impacting on local culture, human welfare and global society, and occurs despite the vastly greater collective knowledge in the population, perhaps because the knowledge of modern individuals tends to be limited to one or two facets of life (Harari, 2011). Following this train of thought, maybe part of the problem of modern agriculture arises from the exclusion of the broader wisdom of earlier generations living a close symbiotic relationship with their natural environment.

The integrated approach to rural development and agricultural intensification proposed in this chapter aims to harmonize the use of modern agrichemicals and genetics with traditional knowledge about tree products. However, in doing so, we must recognize that the public, and specifically the policy makers, donors and agribusiness companies, will not be on our wavelength. This means that more effective communication and better public relations are needed when seeking support for agroforestry. It is interesting, in this connection, that while modern conventional wisdom sees wild fruits and nuts as 'famine foods' of no relevance to life in the twenty-first century, recent evidence from Cameroon indicates that people in the peri-urban population have a strong affinity and desire for indigenous fruits, without any social stigma or shame attached to consumption of wild fruits (Tata epse Ngome, 2015). Furthermore, this study found that the intensification of agriculture on cleared forest lands was associated with hunger and poor diets and with negative impacts on nutritional security and health in the rural population (Tata epse Ngome, 2015).

The socially modified crops developed through multidisciplinary and participatory agroforestry research described in this chapter demonstrate an unconventional approach to agricultural intensification that addresses the environmental, social and economic problems that constrain the productivity of smallholder farming systems in the tropics with potential relevance to the rest of Africa (Leakey, 2017b). It is a low-cost approach which is both easy to apply and has rapid impact (Leakey and Prabhu, 2017). Furthermore, it appears to convert many of the negative trade-offs typically associated with agricultural intensification into positive 'trade-ons' (Leakey, 2018). The generic model has been tested with over 10 000 farmers in 500 communities (Leakey and Asaah, 2013) and could probably be equally well implemented more widely in areas with similar problems, especially as most locations have numerous local species which could be candidates for domestication. Capturing this opportunity would build on the lessons learned from the IAASTD and be in accordance with the 10 principles for sustainable agriculture and the 11 action-oriented targets presented by Leakey and Prabhu (2017). In addition, this upscaling should include capacity building in urban and industrialized societies so that policy makers and agribusiness understand how the needs of farmers and local entrepreneurs can also include better linkages between commerce, industry and international trade. This integrated and multifunctional approach to rural development may also make more effective use of development dollars than current monocultural approaches.

Upscaling agroforestry is about much more than just increasing crop yields. This approach to the sustainable intensification of agriculture simultaneously addresses the many causes of hunger, malnutrition and poverty by combining elements of agroecology, organic farming with conventional agrichemical inputs (Leakey, 2012, 2013), in numerous tree/crop configurations and densities at the plot level, and in landscape mosaics (Fig. 3). It involves the domestication of numerous tree species across sites with very different climates, soils, ethnic groups and indigenous tree species.

Upscaling agroforestry has immediate relevance to current political initiatives in Africa, such as the AFR100 initiative of the African Union to restore 100 million ha of deforested and degraded land (www.wri.org/our-work/project/AFR100/about-afr100). An initiative of this scale will require numerous stakeholder partnerships and alliances engaging the many NGOs and other agencies already active in agroforestry and related approaches to rural development across the continent of Africa (Carbon Farming/Climate Smart Agriculture/Conservation Agriculture/Ecoagriculture/Evergreen Agriculture/Fair Trade/Organic Agriculture/Permaculture etc.). To improve the coordination and common understanding of appropriate strategies and techniques, a new initiative aims to create an overarching alliance – the Agroforestry Alliance for Africa – AAfA) for upscaling sustainable approaches to land rehabilitation and creating more productive and wildlife-friendly farming systems that reduce the pressure on forest/nature reserves.

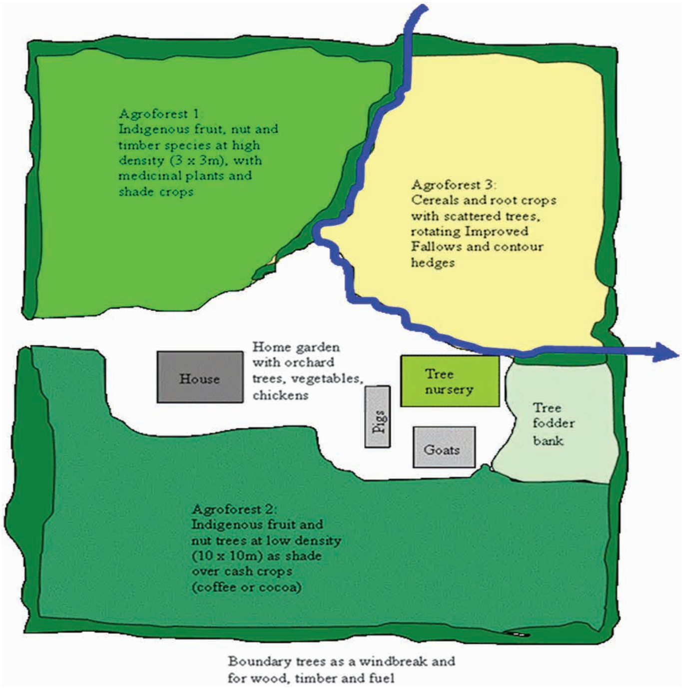

Figure 3 A diagrammatic representation of 'whole farm' agroforestry in which different practices have come together as an integrated approach to maximize economic, social and agroecological benefits (After: Leakey, 2017a).

5.1 Truly sustainable farming systems must avoid economic, social and environmental trade-offs

Conventional thinking accepts that even the sustainable intensification of agriculture often comes hand in hand with many inevitable trade-offs, so the idea that they can be avoided is novel. Quantifying the ability of agroforestry to increase crop production and have economic, social and environmental benefits depends on accurately assessing the impact of its upscaling. This should be based on data collected using randomized and replicated blocks and implemented in partnership with a wide range of NGOs and CBOs through Rural Resource Centres (Degrande et al., 2015).

Typically, tropical smallholders farm primarily for self-sufficiency. Consequently, assessments of economic and social impact should be made on wealth; education; nutritional and medical health; gender equity; land tenure; communal and cultural stability; community cohesion; employment; access to finance, communications, transport, markets and trading associations; and so on as inputs for a risk-averse 'home production' economic model for maximum production efficiency (Ellis and Allison, 2004).

Based on the experience with Rural Resource Centres in Cameroon (Degrande et al., 2015), it seems that smallholder farmers are willing to invest time and effort in appropriate and relevant practical innovations, especially when young people see an opportunity to avoid the need to migrate to big towns and cities for employment.

There are a number of ways of assessing environmental impact. To quantify the restoration of land degradation and ecosystem function, assessments should be made on soil fertility; biodiversity above and below ground; soil structure; carbon sequestration above and below ground; groundwater and freshwater resources; microclimate; and so on. It will also be important to assess differences in the loss of genetic diversity between 'decentralized' village-level and conventional 'centralized' domestication.

In addition to functional biodiversity, there is also great interest in the capacity of agroforestry to conserve threatened species (Perfecto and Vandermeer, 2008) – as an alternative to the creation of protected areas and nature reserves. Likewise, agroforestry can be an effective approach to soil protection and conservation (Saiz et al., 2016) and watershed management. A cost:benefit analysis could then determine the effectiveness of this approach to resolving Africa's environmental, social and economic development. By closing the 'yield gap' arising from conventional agriculture this study might determine how agroforestry can even enhance the returns on past investments in the Green Revolution.

Conventional wisdom suggests that 'trade-offs' between the intensification of agriculture for enhanced food production and its impacts on the environment are inevitable. However, recent evidence has recognized that human well-being and biodiversity can be synergistic (Bennett et al., 2015). However, rather than just accepting this synergy as a desirable indirect benefit, the approach advocated in this chapter suggests that 'trade-ons' achieved by direct action based on innovative and unconventional approaches to agricultural intensification should be deliberately sought as new policy interventions (Leakey, 2018). Research is however needed to further quantify the interactions between all the driving factors.

Unconventional approaches to agricultural intensification are particularly important in Africa. Africa continues to suffer from social and economic deprivation with its associated implications on illegal migration, civil disturbance and perhaps even terrorism. This is a stagnating factor in the global economy and also has serious impacts on the global environment, especially climate change. Much of this can be attributed to agriculture in the tropics and subtropics. A new political mind-set based on relieving the environmental, social and economic constraints to agricultural productivity in Africa could be based on deliberately seeking 'trade-ons', as mentioned above. This would stimulate the local economic development 'in-country', rather than supporting the export-oriented 'globalized trade' model, which in contrast enriches the economy of industrialized countries.

6 Conclusions

Unlike in the industrialized countries, agriculture has failed to be the engine of economic growth in Africa and some other parts of the tropics and subtropics due to failure to recognize the interacting social, economic and environmental that constrain productivity in smallholder farming systems on the brink of the cash economy. To address these constraints there is a need to harness and combine multidimensional environment and production benefits within a global intensification strategy that combines the keystone agroecological role of trees with the ability of local communities to generate income from new business and local industries based on the post-harvest processing, value-addition and trade from traditionally important but overlooked tree products.

It seems that the conventional philosophy of agricultural intensification has blinded policy and decision makers to the opportunities for sustainable intensification based on alternative cropping systems. Change from the current construct which has tried to squeeze tropical smallholders into economic theories designed for large, capital-intensive, businesses open to 'economies of scale' will only become a reality if policy and decision makers 'buy-in' to new concepts and approaches. This is despite numerous reports (e.g. MEA, 2005; IAASTD, 2009; Royal Society, 2009) stating that 'business as usual' cannot be the future of global agriculture.

A new policy mind-set should recognize that global sustainability has to embrace organisms at all trophic levels and scales in agroecological function. Thus, *Homo sapiens* cannot remain outside of the agroecosystem as an external force when intensifying agriculture. This has been recognized by Pimbert (2018) who links agroecology with food sovereignty and biocultural diversity. Meeting the needs of agriculture in this way sees that addressing the overexploitation of planetary boundaries must involve a new approach to intensification. One that combines the needs of people and the planet as suggested in this chapter, should boost food and nutritional security and bring all people around the world into the cash economy.

For this to happen, I suggest that a new international mind-set for tropical agriculture should be based on new socially modified tree crops integrated into smallholder farming systems for both agroecological and income generation. There are numerous, underutilized, 'Cinderella' tree species (Leakey and Newton, 1994) appropriate for domestication and commercialization in this way. This could stimulate local businesses and so raise the median per capita income in developing economies (Fig. 2), and also trigger vibrant new economies in Africa. Interestingly, there are already new food, nutraceutical and pharmaceutical products emerging from the increased awareness of the potential of tropical tree products, which could be expanded if more tropical trees were domesticated using ideotypes targeting new and emerging markets and industries (Fig. 4). This could also be expected to have 'spin-off'

Figure 4 Some of the 50 tree species being domesticated as new crops and some of the products being produced and marketed from new tree crops. Fruits: 1. *Dacryodes edulis*, 2. *Terminalia kaernbachii*, 3. *Allanblackia stuhlmannii,* 4. *Barringtonia procera*, 5. *Vitellaria paradoxa*, 6. *Sclerocarya birrea*, 7. *Adansonia digitata*. Products: 8. Mixed herbs, 9. *Paullinia cupana*, 10. *Bactris gasipaes* fruits, 11. *Bactris gasipaes* palm heart, 12. *Uncaria tomentosa,* 13. *Prunus africana*, 14–15. *Vitellaria paradoxa*, 16. *Santalum austrocaledonicum*, 17. *Prunus africana*, 18. *Pometia pinnata,* 19–20. *Sclerocarya birrea*, 21. *Paullinia cupana,* 22. *Canarium indicum*, 23. *Warburgia salutaris*.

benefits on food sovereignty and the protection of traditional knowledge and related culture.

The outcome from this vision could be a 'greener,' carbon-neutral and more sustainable world feeding and supporting a population well in excess of limits currently anticipated. In addition to addressing the major global issues of hunger, malnutrition and poverty, this could be expected to mitigate against the current levels of social disillusionment, resentment and jealousy that underpin the international security issues of illegal migration, human trafficking and terrorism. The realization of this dream is, however, very unlikely if we continue to plunder natural capital, destroy the local and global environment, and marginalize poor people living in areas where agriculture is failing to meet their social and economic needs.

In this direction, great progress has been made by agroforestry research over the last 25 years with the development and testing of a simple, practical, highly adaptable and generic, three-step model for multifunctional agriculture. This is best implemented in participatory mode by local communities and can reverse the downward spiral of the land degradation and social deprivation cycle, so closing the commonly found yield gap in modern staple food crops.

The approach proposed in this chapter brings together critical elements of modern tree science and the long-known traditional knowledge and culture of local people in a new and innovative approach to resolving many of the big global issues of modern society. Fundamentally these are agricultural reform issues with big environmental, social and economic implications for the planet and humanity which are not addressed by conventional wisdom (e.g. Long, 2015). Thus, it is suggested that this integrated and holistic approach is highly relevant to the simultaneous attainment of many of the 2030 Sustainable Development Goals.

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