22
TWELVE PRINCIPLES FOR BETTER FOOD AND MORE FOOD FROM MATURE PERENNIAL AGROECOSYSTEMS

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ABSTRACT

An analysis of the factors leading to unsustainable agriculture and its associated problems of food insecurity, malnutrition and poverty, identifies a downward spiral of land degradation and social deprivation which is associated with lower crop yields, loss of biodiversity and agro-ecological

function, and declining farmer livelihoods. This spiral is responsible for the Yield Gaps (the difference between the potential yield of a modern crop varieties and the yield actually achieved by farmers) found in many modern farming systems. To reverse this complex downward cycle and close the Yield Gap requires simultaneous crop and soil husbandry, ecological and socio-economic interventions at several different 'pressure-points' within this spiral. This paper advocates 12 important principles for the achievement of food security, which including the adoption of a simple, yet highly adaptable, three-step generic model involving perennial crops to kick-start the reversal of the spiral and so the closure of the Yield Gap. This agroforestry approach involves both the use of biological nitrogen fixation from trees and shrubs, as well as the participatory domestication and marketing of new highly nutritious cash crops derived from the indigenous tree species that provide poor people with the traditionally and culturally important foods, medicines and other products of day-to-day importance. Closing the Yield Gap improves food security by improving the yields of staple crops, but also has beneficial social, economic and environmental impacts. Agroforestry involving the combination of many annual and perennial crop species is, therefore, not an alternative to current agricultural systems, but is a way to diversify and enrich them, making them more sustainable. It does this by increasing food and nutrition security, increasing social and environmental sustainability, generating income, creating business and employment opportunities in rural communities and mitigating climate change. Agricultural policy currently tends not to appreciate these outcomes delivered by tropical and sub-tropical production systems which are based on perennial species and meet the requirements of 'sustainable intensification'.

Keywords: agroforestry, land degradation, tree domestication, poverty, sustainable intensification, yield gap

INTRODUCTION

Agriculture faces a very complex set of social and biophysical issues associated with the economic, social and environmental sustainability. This paper examines the role of perennial species, especially trees, in the attainment of improved staple crop yields; provision of nutritious traditional food; the reduction of poverty, hunger, malnutrition and environmental degradation; the improvement of rural livelihoods; as well as the mitigation of climate change - all with increased economic growth with a programme of Integrated Rural Development (Leakey, 2010; 2012a/b). It therefore provides a model, or policy roadmap, for the delivery of the sustainable intensification of productive tropical and sub-tropical agriculture which is pro-poor and multifunctional – i.e. enhancing agriculture economically, socially and environmentally (Leakey, 2012a). This paper is based on 12 interconnected Principles (Box 1).

BOX 1. TWELVE PRINCIPLES FOR IMPROVED FOOD SECURITY WITHIN MULTIFUNCTIONAL AGRICULTURE AND ENHANCED RURAL DEVELOPMENT

	PRINCIPLES
1	Ask, do not tell
2	Do not throw money at farmers, but provide skills and understanding
3	Build on local culture, tradition and markets
4	Use appropriate technology, encourage diversity and indigenous perennial species
5	Encourage species and genetic diversity
6	Encourage gender/age equity
7	Encourage farmer-to-farmer dissemination
8	Promote new business and employment opportunities
9	Understand and solve underlying problems: The Big Picture
10	Rehabilitate degraded land and reverse social deprivation: Close the 'Yield Gap'
11	Promote 'Multi-functional Agriculture' for environmental/social/economic sustainability and relief of hunger, malnutrition, poverty and climate change
12	Encourage Integrated Rural Development

PRINCIPLES

PRINCIPLE 1. Ask farmers what they want, do not tell them what they should do.

As the human population has grown, shifting cultivation has become less and less sustainable as deforestation has made new productive land scarcer. One consequence of this has been that farmers have been forced to become more sedentary. With this their crop yields have declined and farmers have struggled to feed their families, let alone generate income from surplus production. These families have therefore becoming increasingly trapped in hunger, malnutrition and poverty and are in need of help and substantial policy reform to free them from the circumstances that they are in. The problem originates with the advent of colonialism and the industrial revolution, because there has been a tendency for leaders in developed countries to think that agricultural developments that have worked in the temperate zone must be applicable in the tropics; despite big differences in the climate, soils, ecology and socio-economic conditions. As a result agricultural policy in developing countries has often been based on a model that is not well adapted to local conditions.

Recognizing the above issue, the work reported here began with a participatory approach to priority setting (Franzel *et al.* 1996; 2008) that sought the ideas of farmers on what they needed. These farmers identified their desire to grow the forest species from which, as hunter gatherers and subsistence farmers, they had formerly gathered wild fruits, nuts and other products of everyday value (Leakey, 2012a). This has led to an unconventional approach to agricultural development

that focuses on the domestication of indigenous fruit and nut trees using a participatory approach. From this initiative the following principles have emerged (Tchoundjeu *et al.* 2002; 2006; 2010; Leakey *et al.* 2003; Asaah *et al.* 2011; Degrande *et al.* 2006; Leakey and Asaah, 2013).

PRINCIPLE 2. Provide appropriate skills and understanding, not unsustainable infrastructure.

Many agricultural and other rural development projects provide funding for communities to implement new and 'improved' technologies – often ones based on concepts which are 'foreign' to the farmers. While the funds are flowing these projects can be successful, but very often when the project comes to an end the new approaches are not sustained. Typically this is because the stakeholders are still dependent on a continuing stream of finance, but this is often exacerbated by a lack of 'buy-in' to the new approach. To try to overcome these problems the work reported here first asked farmers what they wanted and then, once that was agreed, went on to assist by providing skills and understanding through training, but without direct financial assistance. Thus project funds were spent on training and mentoring the participating communities with only the provision of minimal facilities. Then, as the concepts were adopted and the programme grew, these facilities were improved by both donor funds and by community contributions. In this way, pilot village nurseries grew into Rural Resource Centres staffed by village members with support from local NGOs and Community Based Organizations (CBOs) (Tchoundjeu *et al.* 2006, 2010; Asaah *et al.* 2011). This has been found to be an effective strategy for the dissemination of agroforestry innovations (Degrande *et al.* 2012).

PRINCIPLE 3. Build on local culture, tradition and markets.

In the past, tree products were gathered from natural forests and woodlands to meet the everyday needs of people living a subsistence lifestyle. Non-timber forest products gathered from the wild in this way have played an important role in the lives and culture of local people, as is recognized by the study of local flora (e.g. Abbiw, 1990) and ethno botany (Cunningham, 2001) With the application of intensive modern farming systems this resource has declined. To rebuild and improve this useful resource the concept of tree domestication for agroforestry was proposed in 1992 (Leakey and Newton, 1994) and subsequently implemented by the World Agroforestry Centre (ICRAF) as a global initiative from 1994 (Simons, 1996). Great progress has been made in the first two decades of this initiative (Leakey *et al.* 2005; 2012) which have encouraged local entrepreneurism in the processing and marketing of agroforestry tree products. This has had beneficial impacts on farmers' livelihoods (Tchoundjeu *et al.* 2010; Leakey, in press a).

To capitalize on this tradition and culture, the domestication of indigenous fruit and nut trees for integration into farming systems through agroforestry is based on participatory processes

involving local communities. The prime objective of the participatory approach is to involve the target communities in all aspects of the planning and implementation of the programme so that they have ownership of the programme, while also benefitting from the close involvement of researchers and NGOs as mentors in the domestication programme. By building on tradition and culture in this way, participatory tree domestication has stimulated rapid adoption by growers and has enhanced the livelihoods of the households and communities involved (Leakey *et al.* 2003; Simons and Leakey, 2004; Asaah *et al.* 2011).

In implementing this strategy it is of great importance to recognize the legal and socially-important communal rights of local people to their traditional knowledge and local germplasm (Lombard and Leakey, 2010) and to ensure that they benefit from their use and are rewarded for sharing them for the wider good. Because of the sensitivity arising from past commercial exploitation of these rights by individuals, companies, academics, international agencies and government, it is very clear that the partners in domestication programmes have to earn the trust of local communities. This is to ensure that benefits flow back to the farmers and communities, the recipients of traditional knowledge and germplasm should enter into formal 'Access and Benefit Sharing' agreements (ICRAF 2012) in which the rights of the holders of knowledge and genetic resources will be legally recognised.

With poverty alleviation as one of the objectives of the domestication of indigenous trees it is clear that incentives for, and approaches to income generation are important in the overall strategy. Consequently, improving and expanding the markets for agroforestry trees and their products are central to the strategy. The experience of the last 10-15 years indicates that this is transforming the lives of the participating farmers and helping them to break-into new business and employment opportunities (Leakey and Asaah, 2013).

In many countries land tenure systems are complex with a combination of community customary rights and individual legal rights based on land purchase. In addition, government attempts to regulate logging and deforestation make the sale of tree products illegal. These issues can affect farmers' decisions about the growth of tree crops. In Cameroon, a study of formal policies found that regulations do not clearly distinguish between products from trees found in the wild and those gathered from farmers' fields (Foundjem-Tita *et al.* 2012). This finding supports the need to distinguish between common-property wild forest resources (e.g. non-timber/wood forest products) and private domesticated tree resources (agroforestry tree products) growing in farmland (Simons and Leakey, 2004) and to recognise that the exploitation, transport, import and export of indigenous fruit crops from farmers' fields do not pose any threat to conservation (Schreckenberg *et al.* 2006b). Defining agroforestry tree products (timber and non-timber) as conventional farm products in this way should increase farmers' incentives to formally cultivate trees and harvest their products, with beneficial impacts on farmers' income, national revenues, rehabilitation of degraded land and the environment (Schreckenberg *et al.* 2006a).

A strategy to increase income generation from the sale of tree products in local markets is particularly important as local people are familiar with the use of these food and medicinal products and the demand typically exceeds supply. In the longer term, this trade often has potential to expand regionally and even internationally as the products become more widely known or better processed for global customers. However, as the commercialization process involves more players and becomes more complex, so the risks that producers will be exploited increases. To counter this risk, innovative approaches to ensure that farmers and local communities are rewarded for their marketing innovations have been developed by PhytoTrade Africa and are being extended to tree domestication (Lombard and Leakey, 2010; Leakey, in press a). Again, the approach involves working with indigenous communities and helping them to secure long-term access to markets in ways which reward them and protect their intellectual property rights.

PRINCIPLE 4. Use appropriate technology and indigenous perennial species.

Principles 1 and 3 mentioned the relevance of indigenous trees and their products to tropical and sub-tropical farmers. To capture, harness and improve the flow of benefits from these trees recent approaches to their domestication have focussed on the large opportunity for genetic selection and clonal propagation as horticultural cultivars. This is based on the capacity of vegetative propagation to capture and fix desirable traits, or combinations of traits, found in individual trees (Leakey and Simons, 2000). This approach to clonal propagation also has the benefit that selected trees can be propagated from mature tissues so that the cultivar has a lower physical stature and early fruiting - making early returns on effort and the harvesting of fruits easier.

The simplest technique for mass clonal propagation is the rooting of leafy stem cuttings. Studies over the last 50 years have greatly enhanced the understanding of basic principles for robust and efficient techniques (Leakey, 2004; in press b), as well as the development of simple, low-cost propagation systems for implementation in remote village nurseries without access to running water and electricity (Leakey *et al.* 1990). With only a little training, these propagators made from locally available materials have been widely and successfully adopted around the tropics by unskilled and illiterate farmers and have opened up the opportunity to develop improved clones/cultivars of over 50 tree species for local planting, as well as for sale to others. Without this appropriate technology participatory tree domestication would probably not have been possible.

To decide which trees have potential for cultivar development it is necessary to have an understanding of the tree-to-tree variation within wild populations. Fortunately farmers who have gathered products from the wild trees in their area are generally well aware which trees have particular traits, such as large fruit or nut size, good taste, or particular elements of seasonality – all desirable traits that attract a good market price (Figure 1). To assist this process of farmer selection, appropriate quantitative techniques have also been developed

for the selection of superior trees that meet the needs of local markets and industries. The tree-to-tree variation in hundreds of morphological traits of importance to the development of food, cosmetic, pharmaceutical and other products have been assessed in the field and used to identify appropriate multi-trait combinations that can be easily understood by local farmers. Scientific studies of chemical and physical traits have been done in parallel and the results of these are used to assist farmers to understand the potential for the development of new commercial products. The above scientific inputs to the understanding of genetic variation can then inform the process of farmer selection and help to provide guidance of how best to meet the needs of different market opportunities. Based on the concept of 'ideotypes' for tree selection (Leakey and Page, 2006) cultivars can be developed that have the ideal combination of traits for a product to meet the needs of a particular market. So, for example an ideotype for a fresh fruit would have a lot of flesh (and small seeds/nuts/kernels), be sweet, juicy, tasty, nutritious and look attractive. On the other hand, a nut ideotype would have a large kernel(s) (and probably little flesh), have a thin shell so that it is easily cracked, be rich in edible oil with an appropriate fatty acid profile or have other characteristics meeting the needs of the cosmetic or pharmaceutical industries. In both instances, these quality traits are ideally associated with a high yield of fruits or nuts, so that the cultivar can be said to have a high 'harvest index' – a large amount of 'ideal' harvestable product.

FIGURE 1. FRUITS OF SAFOU (*DACRYODES EDULIS*) FROM A MARKET IN YAOUNDÉ IN CAMEROON, WITH THEIR ASSOCIATED PRICE WHICH RECOGNIZES BOTH SIZE AND FLAVOUR

***c.f.* three fruits selling for 250CFA *versus* 22 fruits selling for 50CFA.**

To assist the marketing of tree products (especially nuts), simple, low-technology tools are being developed for nut cracking and the pressing of oil from nut kernels (e.g. Mbosso *et al.* in press). These are labour saving, better for large scale processing and safer than many tradition methods, such as the use of a machete to extract kernels.

PRINCIPLE 5. Encourage species and genetic diversity.

Of the 20 000 plant species producing edible products only about 0.5 percent have been domesticated as food crops, yet many have the potential to become new crops through the implementation of participatory domestication; indeed research is already in progress in over 50 tree species (Leakey *et al.* 2012). Adding new crops to small farms reduces risks from crop and market failures, as well as playing an important role in the re-building of agro-ecological functions on degraded farm land (Leakey, 1999b; 2012a). In environmental terms, the diversification with long-lived perennial plants is important because it is the way to rebuild the ecological functions of agro-ecosystems and landscapes.

Some people are rightly concerned that the domestication of new food crops will result in the loss of their genetic diversity by narrowing the genetic base. This can certainly happen if the domestication process is not based on a wise strategy that is correctly implemented. In the case of agroforestry trees being domesticated by participatory processes implemented at the village level, there is good evidence that both the strategy (Leakey and Akinnifesi, 2008) and the implementation (Pauku *et al.* 2010) are not creating any serious concerns. About 70-80 percent of the tree-to-tree variation is found at the village level and selected trees with morphologically desirable traits have been found by DNA analysis to be unrelated. Consequently, development of different sets of unrelated cultivars in different villages ensures that the narrowing of the genetic base is minimal. In other words "decentralized domestication" seems to be a means of ensuring genetic diversity is retained.

Furthermore, by gaining an understanding of the tree-to-tree variation and developing different sets of cultivars based on ideotypes formulated to meet the needs of different markets it should be possible to repackage genetic diversity and develop cultivars which are as different from each other as breeds of dogs are different from each other (Leakey, 2012a), without destroying the wild species.

In the scientific approach to selection, modern laboratory techniques are being increasingly used to examine traits which are not visible to the naked eye. For example, to quantify genetic variation in the chemical and physical composition of marketable products such as polysaccharide food thickening agents, nutritional content (protein, carbohydrate, oils, fibre, vitamins and minerals, etc.) by proximate analysis, medicinal factors like anti-inflammatory properties, the composition of essential oils and fatty acids, the determination of wood density, strength, shrinkage, colour, calorific value and other important wood properties correlated with tree growth (Leakey *et al.* 2012). Molecular DNA analysis is increasingly being used to gain understanding of genetic variation and relatedness (Jamnadass *et al.* 2009).

PRINCIPLE 6. Encourage gender and age equity.

In many rural communities around the world, women in particular have been engaged in gathering, using and marketing tree products. One of the purposes of a participatory tree domestication strategy is to ensure that all members of the community, whether male or female, are empowered by the programme and the beneficiaries of the outputs of their own initiatives and labour. This has been found to enhance the livelihoods of the community members in general and promote social and gender equity (Kiptot and Franzel, 2012), with exciting long-term benefits for youths (Leakey and Asaah, 2013; Degrande *et al.* 2012).

PRINCIPLE 7. Encourage farmer-to-farmer dissemination.

Through the development of Rural Resource Centres as the hubs of participatory tree domestication there has been a steady growth in the number of communities (from two to over 450) and number of people (from 20 to over 10 000) becoming engaged in participatory tree domestication as satellite nurseries have been developed in the areas around the Rural Resource Centres (Tchoundjeu *et al.* 2006) - a process which in continually expanding (Asaah *et al.* 2011). Much of this has been word-of-mouth neighbour-to-neighbour dissemination, but in addition efforts have been made for longer distance dissemination by community-to-community visits, fairs and competitions, as well as stories in the national media.

Evidence from Cameroon (Degrande *et al.* 2012) suggests that the involvement of grassroots organizations in the extension of agroforestry through the Rural Resource Centres has led to a relatively high level of satisfied farmers and been successful in reaching the women and youths often excluded by other extension systems.

PRINCIPLE 8. Promote new business and employment opportunities.

As mentioned earlier, local markets often exist for traditionally important food and non-food products from trees. Thus local knowledge and acceptance of the products is good. Again as mentioned, through the application of the 'ideotype' concept (Leakey and Page, 2006), tree domestication enhances the quality, uniformity and marketability of these products as clonal cultivars, selected for commercially desirable traits, stimulate a quantum leap in the marketability of the products. This means that traders and wholesalers can purchase a large volume of uniform, high quality product from a recognized and named cultivar. In return, hopefully the producer will receive a higher price, as it is clear that consumers are willing to pay more for the more desirable varieties. To ensure that these price benefits are passed back to the small-scale community producers, the development of trade associations, business partnerships and agreements are essential (Lombard and Leakey, 2010). Interestingly the benefits from tree domestication become increasingly important as the value chain progresses from local to global (Leakey and

van Damme, in press). In the case of marketing Njangsang (*Ricinodendron heudelottii*) kernels in Cameroon more kernels were traded, with faster integration and greater financial benefits when interventions to enhance commercialization were implemented (Cosyns *et al.* 2011). Other relevant evidence from Cameroon suggests that the adoption of collective action in kola nut production is influenced by its ease of use, absence of entry barriers and emphasis on social activities which serve as an intrinsic motivator for farmers (Gyau *et al.* 2012).

Much work remains to be done to select cultivars for year-round production and to develop post-harvest technologies for the extension of the shelf life of agroforestry tree products and processing for added value. Interestingly, there are a growing number of processed tree products on regional and international markets – for example there are over 410 Baobab products (PhytoTrade Africa, www.phytotradeafrica.org). Many of these products rely on wild harvesting for their supply; this supply can be of very variable (non-uniform) and of mixed quality, as well as irregular across seasons and producers.

With the increasing importance of market acceptability, exclusivity and distinctiveness the use of ideotypes for the identification of the specific trait combinations become more and more critical. To meet this demand increasingly sophisticated research to determine the genetic variation in the chemical, physical and medicinal properties of the raw products is underway (Leakey *et al.* 2012). This also leads to the need for stronger linkages between agroforestry researchers and partners in industry (Leakey, 1999a), as can be seen in the case of Allanblackia oil (Jamnadass *et al.* 2010).

PRINCIPLE 9. Understand and solve underlying problems – the Big Picture.

Over the last 60 years, agricultural intensification has resulted in substantial gains in crop and livestock production. These are due to advances in breeding (e.g. genetic gain, stress resistance), husbandry (e.g. fertilizer, irrigation, mechanization), policy (e.g. Intellectual Property Rights, variety release processes), microfinance (e.g. credit, provision of inputs), education and communication (e.g. farmer-field schools), and market and trade (e.g. demand, incentives). World cereal production, for example, has more than doubled since 1961, with average yields per hectare also increasing around 150 percent (with the notable exception of sub-Saharan Africa). Likewise, modern agriculture has led to great improvements in the economic growth of many developed countries, with concomitant improvement in the livelihoods of many farmers. In real terms, food has become cheaper (although currently prices are increasing) and calorie and protein consumption have increased. Thus, on a global scale, the proportion of people living in countries with an average per capita intake of less than 2200 kcal per day has dropped from 57 percent in the mid-1960s to 10 percent by the late 1990s.

However, these benefits have come with a high environmental cost and only marginal improvements in reduced poverty, malnutrition and hunger in developing countries. Some of the major issues affecting global agriculture are:

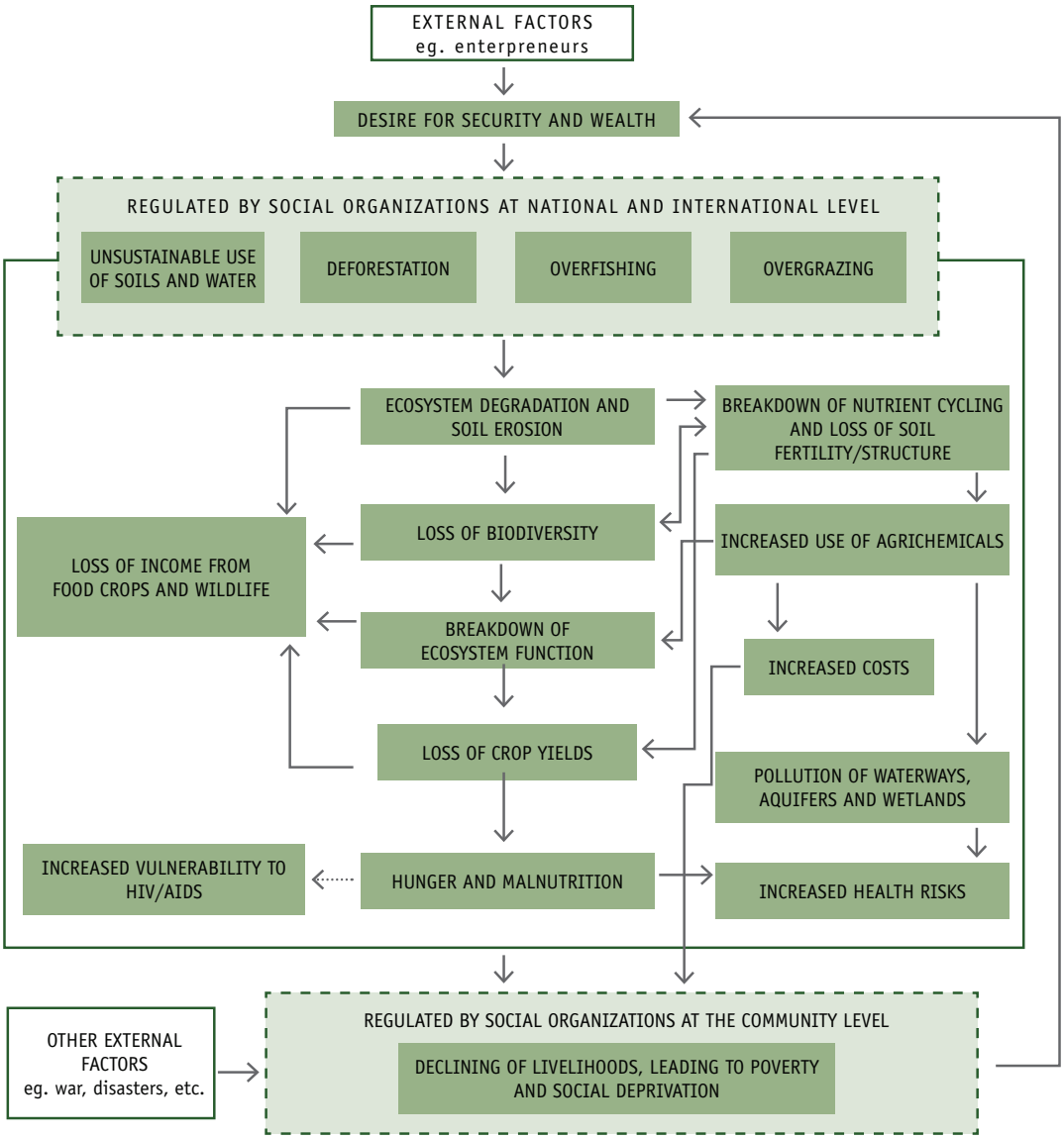
- The scale of natural resource degradation (affecting 2.6 billion people and 2 billion ha of farm land), the depletion of soil fertility (nitrogen, phosphorus, and potassium deficiencies affecting 59, 85 and 90 percent of crop land, respectively), loss of biodiversity (valued at US$1 542 billion/yr), depletion of water resources (2 664 km^3/yr) and agro-ecosystem function, against a background in which new land for agriculture is increasingly scarce. This situation, which has arisen from the over-exploitation of natural capital, makes the rehabilitation of farm land, and its associated natural assets, an imperative.
- The incidence of poverty (3.2 billion people with an income of less than US$2/day), malnutrition, and nutrient deficiency (2 billion people) and hunger (0.9 billion people) remain at unacceptable levels, despite the very significant improvements in agricultural production. In addition, 1 billion people are affected by obesity due to poor diet.
- There are numerous organizational and conceptual "disconnects" between agricultural disciplines and organizations, especially those responsible for environmental services and sustainable development. Agricultural production and governance have focused on producing individual agricultural commodities rather than seeking synergies and the optimum use of limited resources through technologies promoting integrated natural resources management and multifunctional agriculture.
- Modern public-funded agricultural knowledge, science, and technology research and development has largely ignored the improvement of traditional production systems based on "wild" resources which, traditionally, have played an important role in peoples' livelihoods.
- Agriculture is responsible for 15 percent of greenhouse gas emissions.
- Since the mid-20th Century, the Globalization pathway has dominated agricultural research and development as well as international trade, at the expense of the "Localization" benefits of many existing small-scale activities of farmers and traders that are aimed at meeting the needs of poor people at the community level.

Together, these issues contribute to the formation of a downward cycle of land degradation and associated social deprivation (Figure 2) that drive down crop yields and suppress farmers' livelihoods, which together are responsible for a Yield Gap (Figure 3) between the biological potential of modern crop varieties and the yield that poor farmers typically manage to produce in the field (Leakey, 2010, 2012a).

An analysis of the cycle of land degradation and associated social deprivation recognizes that the cycle is driven by a desire for security and wealth, which in turn drives deforestation, overgrazing and unsustainable use of soils and water: all of which cause agro-ecosystem degradation (Leakey, 2010, 2012a). In farmers' fields this is seen as soil erosion, breakdown of nutrient cycling and the loss of soil fertility and structure. The consequence of this degradation is the loss of biodiversity, the breakdown of ecosystem functions and the loss of crop yield. Low crop yields result in hunger, malnutrition, increased health risks and a loss of income, all of which are manifest as declining livelihoods and so return the cycle to a desire for security and wealth. It is recognized that at all of the steps within this conceptual diagram, there are a range

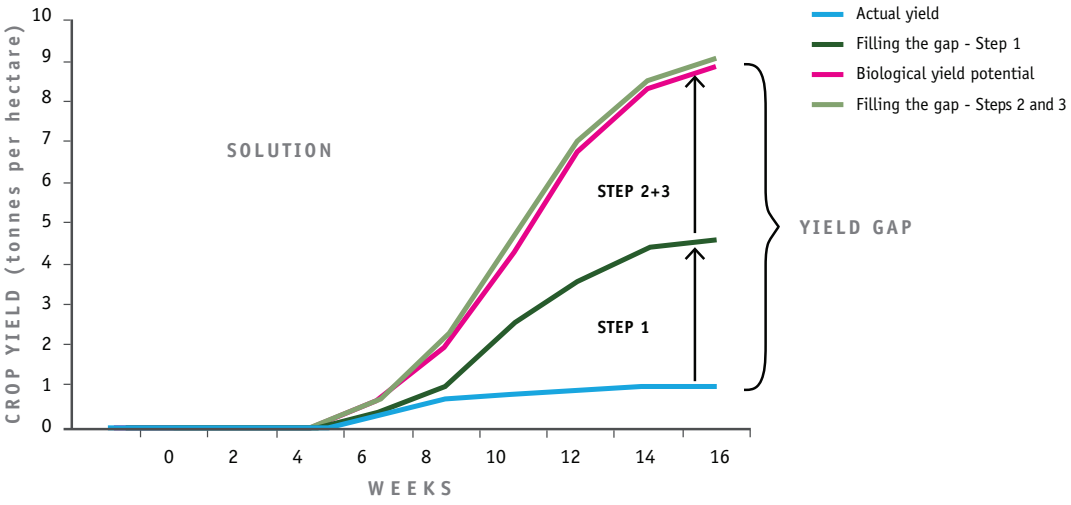
of socio-economic and biophysical influences which will determine the speed of the downward progress at any particular site. Such factors include: access to markets, land tenure and local governance - not to mention external factors such as natural disasters, conflict and war, and economic drivers such as international policy and trade agreements.

FIGURE 2. DIAGRAMMATIC REPRESENTATION OF THE CYCLE OF LAND DEGRADATION AND ASSOCIATED SOCIAL DEPRIVATION



Source: Leakey, 2012a.

FIGURE 3. DIAGRAMMATIC REPRESENTATION OF THE YIELD GAP AND THE STEPS REQUIRED TO CLOSE THE GAP



Source: Leakey, 2012a.

PRINCIPLE 10. Rehabilitate degraded land and reverse social deprivation: Close the Yield Gap.

To be productive, conventional approaches to modern agriculture typically require large inputs of fertilizers, pesticides, mechanization and, in dry areas, irrigation. However, the dependence of this type of agriculture on income and financial capital makes it inaccessible to hundreds of millions of poor farmers due to their high cost and local availability. As it is clear that cutting more forest down for agriculture is not an acceptable option, it is crucial to find ways of making degraded land productive again. Unfortunately, agricultural research and development has focused more on increasing potential yield than on addressed the cycle of land degradation and social deprivation that creates the Yield Gap.

To close the Yield Gap, Leakey (2010, 2012a) has suggested the following three-step approach as a way forward, using example of maize (*Zea mays L.*) production in eastern and southern Africa. The approach is based on the use of agroforestry fallows, perennial crops, tree domestication, and the marketing of agroforestry tree products as a way deliver multifunctional agriculture:-

- **Step 1.** Adopt agroforestry technologies such as two year improved fallows or relay cropping with nitrogen-fixing shrubs that improve food security by raising maize yields four-fold from around 1 Mg ha-1 (Buresh and Cooper, 1999; Sileshi *et al.* 2008). Likewise, stands of *Faidherbia albida* (Del.) A. Chev. trees play a similar role in the so-called Evergreen Agriculture (Garrity, 2012; Swaminathan, 2012). This allows the farmers to reduce the area

of their holdings planted with maize and so make space for other crops, perhaps cash crops which would generate income. This diversification could also include the establishment of perennial grains. An additional benefit arising from improved fallows with leguminous shrubs like *Sesbania sesban* (L.) Merr. and *Desmodium* spp. is the reduction of parasitic weeds like *Striga hermonteca Benth*., and the reduced incidence of insects pests like the stem borers of maize (Cook *et al.* 2007).

- **Step 2.** Adopt the Participatory Domestication of indigenous trees producing marketable products, so that new, locally important and nutrient-rich cash crops are rapidly developed as a source of income and products of day-to-day domestic importance, and help empower women and maintain culture and traditions (Cooper *et al.* 1996; Sanchez and Leakey, 1997). Sale of these products would allow the purchase of fertilizers and so, potentially, the increase of maize yields up to 10 Mg ha-1. Consequently, the area under maize could be reduced further to allow more cash cropping. Filling the Yield Gap will also maximize returns on past investments in food crop breeding.
- **Step 3.** Promote entrepreneurism and develop value-adding and processing technologies for the new tree crop products, so increasing availability of the products throughout the year, expanding trade and creating employment opportunities – outputs which should help to reduce the incidence of poverty.

This approach, which is based on good land husbandry to rebuild natural soil fertility and health, therefore increases food security by improving crop yields. However, it does more than that. The inclusion of trees and other perennial crops within farming systems increases the number of niches in the agro-ecosystem. These are filled by a wide range of organisms (the unplanned biodiversity) in ways that improve nutrient, carbon and hydrological cycles; enrich food chains and meet the needs of more complex food cycles, and reduce the risks of pest and disease outbreaks. As the trees increase in size and the ecosystem progresses towards maturity, the numbers of niches for further ecosystem diversity continues to increase further enhancing agro-ecosystem function and services. This diversification makes these farming systems less damaging and more sustainable. The high species diversity of moist and dry tropical forests and woodlands means that there are many species available to play these important ecological roles in a developing agro-ecological succession (Leakey, 1996). The domestication of indigenous trees as new crop plants offer opportunities to increase the numbers of cultivated plants (the 'planned biodiversity') in these systems in ways that increase the wild organisms (the 'unplanned biodiversity') that fills the niches in the diversified farming system. The new crops of course also provide products to meet the social and economic needs of poor farmers (70 percent of the 3.2 billion people living on less than US$2 per day) for food self-sufficiency, micronutrients, medicines and all their other day-to-day needs not provided by modern monocultures. An important part of this approach is therefore to 'hedge' against environmental and ecological risk and provide the livelihood needs of the local communities.

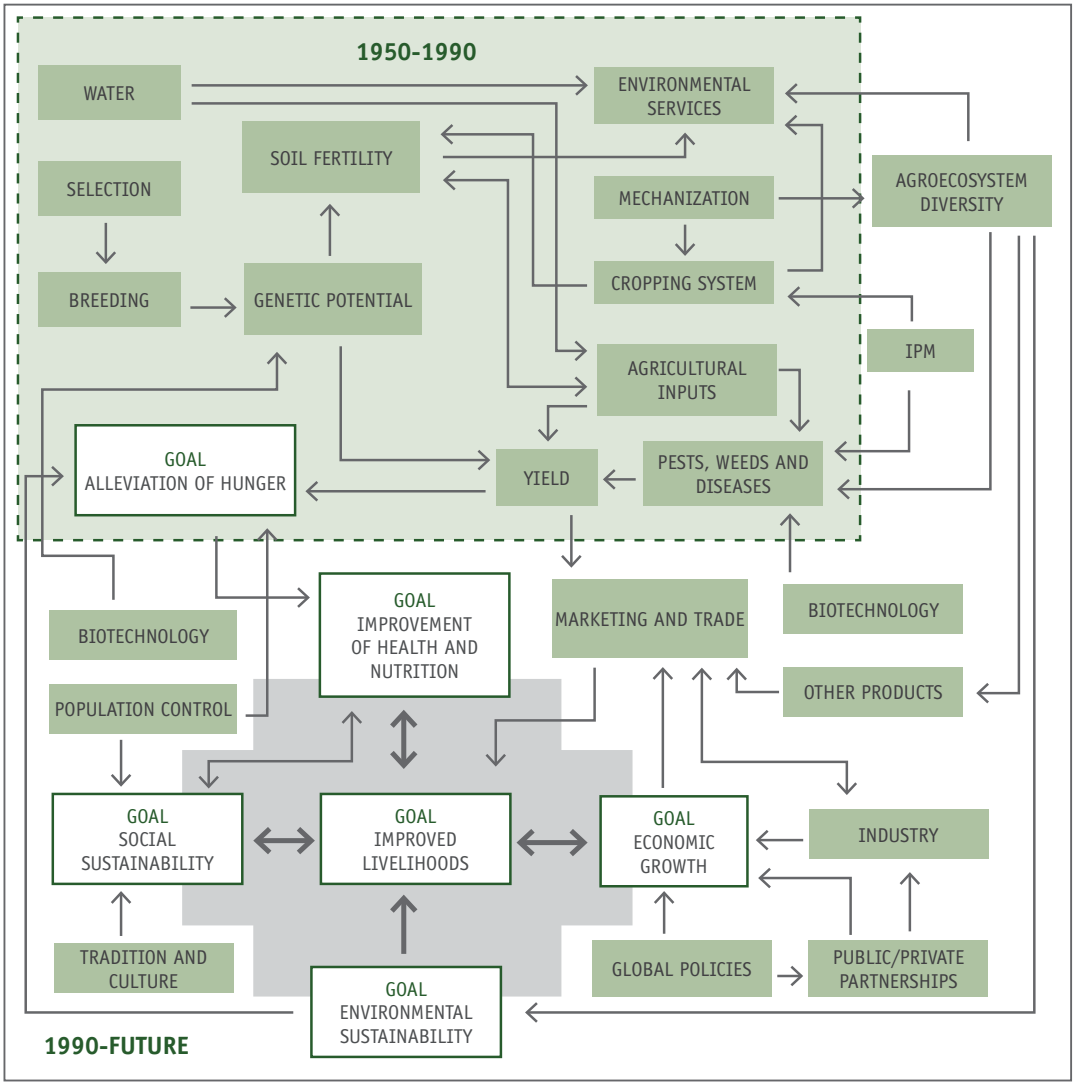
By including the domestication of traditional food species and the marketing of their products, this approach also meets the needs of the community for micronutrients that mitigate malnutrition and boost immunity to diseases (Leakey *et al.* 2012; Leakey, 2012a/b). Concomitantly, the commercialization of the tree products matches the product value chain to the needs of traders for more uniform and higher quality products with improved shelf life. This emphasis on enhanced trade is then being found to open up a pathway out of poverty based on new sources of employment and new local business opportunities (Leakey 2012a). So, as a package, this combination of social- and economic advancement with the environmental restoration creates a generic model for closing the Yield Gap – a model which is highly adaptable to a very wide range of climatic and edaphic environments and to numerous socio-economic situations, on account of the very large numbers of candidate tree species appropriate to all environments (Leakey, 2010; Leakey, 2012a,b).

PRINCIPLE 11. Promote 'Multi-functional Agriculture' for environmental/social/economic sustainability and relief of hunger, malnutrition, poverty and climate change.

Multifunctional agriculture, as described by International Assessment of Agricultural Science and Technology for Development (IAASTD) (McIntyre *et al.* 2008), has the objective of simultaneously promoting the social, economic and environmental benefits of farming systems. In other words, agriculture is very much more than just the production of food (Figure 4).

Agroforestry is particularly relevant to the delivery of multi-functional agriculture as it addresses: (i) environmental issues: (a) soil fertility management, (b) the rehabilitation of degraded farming systems, (c) loss of biodiversity above and below ground, (d) soil and watershed protection, (e) carbon sequestration and (f) energy needs through the provision of wood fuel; (ii) Economic issues: (a) income generation through trade in useful and marketable tree products, (b) the creation of business and employment opportunities in trade and value-adding through the processing of tree and non-tree products and (c) the creation of new cottage industries for diversification and enrichment of the rural economy; (iii) Social issues: (a) lack of gender equity and the need for community empowerment, (b) urban migration, (c) poverty and health related problems, (d) loss of cultural identity and of Traditional Knowledge, (e) loss of food sovereignty, (f) the lack of income for better education and training, provision of essential skills, and (g) the lack of income for community projects such as the supply of potable water, community infrastructure developments, transport, etc.

FIGURE 4. DIAGRAMMATIC REPRESENTATION OF MULTIFUNCTIONAL AGRICULTURE AND ITS GOALS.



Together, the above benefits help to resolve the higher level livelihood issues of: (i) a lack of food and nutritional security - and associated poor health, (ii) extreme and widespread poverty, (iii) the loss of self-esteem arising from the marginalization of poor communities by the social elite and the consequent vulnerability to exploitation arising from a lack of self-sufficiency, (iv) deforestation and over-exploitation of natural resources, (v) the lack of available productive land due to the degradation of complex mature and functioning agro-ecosystems and

the fragmentation of agricultural landscapes (Perfecto and Vandermeer, 2010; Leakey, 2010; van Noordwijk *et al.* 2012).

With the increasing recognition of the need to address climate change the integration of trees in farming systems is being recognized as crucial for the reduction of greenhouse gas emissions and climate smart agriculture (Nair, 2012; van Noordwijk *et al.* 2011). Large perennial trees have a high volume of standing biomass and through litter fall and root turnover they also enrich the soil with carbon (Minang *et al.* 2012). Studies suggest that the conversion of degraded farm land to mature agroforest could increase carbon per hectare from 2.2 to 150 mg over a potential area of 900 million ha worldwide (World Agroforestry Centre, 2007).

So, we see that by using agroforestry to resolve the production, food and nutritional security and poverty issues causing the Yield Gap we simultaneously move farming systems towards the objectives of multifunctional agriculture and create an approach to tropical agriculture which both builds on the positive outcomes of the last 60 years of the Green Revolution, and addresses some of its negative outcomes. As a consequence, tropical agriculture becomes more productive – a process of intensification - yet environmentally, socially and economically more sustainable that the current conventional approach to modern agriculture (Leakey, 2012c).

PRINCIPLE 12. Encourage Integrated Rural Development.

So far, we have seen that agroforestry has two important roles in the development process relating to agriculture and the rural economy: i) it provides techniques for the implementation of a highly adaptable set of three steps for the closure of the Yield Gap that includes value-adding within the marketing of a wide range of indigenous tree products from mixed farming systems, and ii) it is a delivery mechanism for intensified multifunctional agriculture. While these are big steps towards more sustainable rural development, they need to be set within an even wider context in which agroforestry and multifunctional agriculture are part of a regional programme of integrated rural development.

To pull the above 11 principles together into a single project, the World Agroforestry Centre in Cameroon initiated a development programme in 1998 centred around the provision of training in agroforestry for the rehabilitation of degraded land and the domestication/commercialization of fruits and nuts from indigenous trees. This was implemented in a participatory manner through Rural Resource Centres which in addition provided training in nursery management, entrepreneurism and the use of microfinance, community organization and infrastructure development, fabrication of simple tools and equipment for value-adding tree and non-tree food products and the expansion of the value chain for traditional food products.

In this longest-running example of participatory domestication in agroforestry trees the researchers fed their outputs to NGO partners through training-of-trainers courses and by acting as mentors to the NGO-managed Rural Resource Centres established in pilot villages (Tchoundjeu

et al. 2002, 2006, 2010; Asaah *et al.* 2011). The farmers in this partnership contributed their knowledge about the use and importance of local species, the range of variation in different traits of relevance to genetic selection and their Traditional Knowledge about the role of these species in local culture and tradition. They have also contributed their time and labour. Furthermore and crucially, they also made available some of their trees for research and for training in domestication techniques.

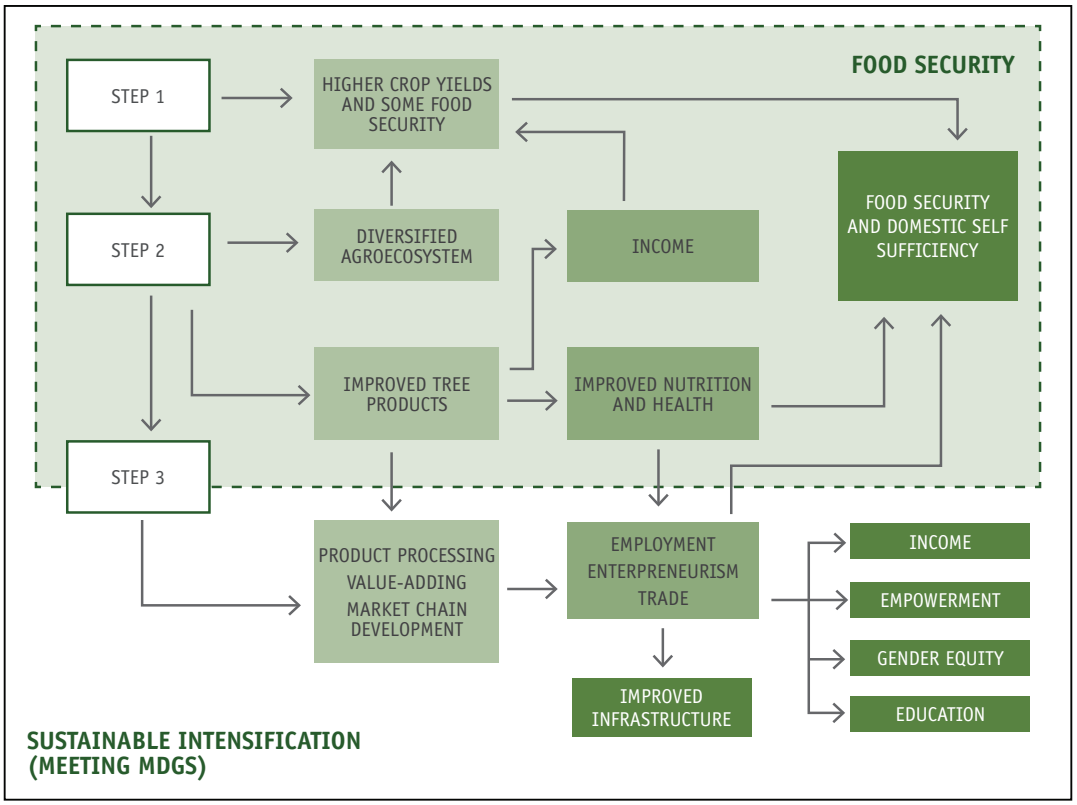
This case study - a winner of the prestigious Equator Prize – now involves more than 10 000 farmers and over 200 communities in the West and North-west regions of Cameroon, as well as entrepreneurs in local towns. The project is centred on five Rural Resource Centres which are providing a wide range of training to farmers through the growth of more than 120 satellite tree nurseries in surrounding communities supported by Relay Organizations (NGOs, CBOs, etc.) in the villages. The experience of the last 15 years indicates that the first income stream from agroforestry projects is derived from the sales of plants from village nurseries to neighbouring communities; and especially the sale of seedlings of nitrogen-fixing or the so-called 'fertilizer' trees (Asaah *et al.* 2011; Leakey and Asaah, 2013). In terms of soil fertility replenishment, the benefit flows from these trees are obtained relatively quickly (crop yield up two to three-fold in 2-3 years). On the other hand, it generally takes longer (>4 years) to obtain returns from the production and sale of the tree products. On average, results to date indicate that farmers' income from the sale of plants from village nurseries has risen dramatically as the project gathers momentum (US$145, US$16 000 and US$28 350 after 2, 5, and 10 years, respectively).

In addition, to overcome one of the constraints to better food processing local metal workers in nearby towns have been supported to develop appropriate equipment for drying, chopping, and grinding a range of foodstuffs, including tree products not previously processed. The tree products are selling at higher than usual prices and in a few cases are being sent abroad. This component of the programme has created employment for metal workers and allowed local entrepreneurs to extend the shelf life and the quality of the produce they sell in local markets. For example, the fabrication of about 150 discharge mills and 50 dryers has generated income in excess of US$120 000 (Asaah *et al.* 2011; Leakey and Asaah, 2013). In parallel, women in nearby towns have set up businesses for grinding crops like cassava (*Manihot esculenta*) have also increased their income substantially. The largest of these groups was run by ten women who employed eight workers and processed about sixty-six 180kg-bags of dried cassava flour per day throughout the year. Profits from bags selling at US$40-US$54 per bag, depending on the season, were said to be more than US$2.5 per bag. When integrated with developments across in the agricultural sector, small business developments such as these benefit from linkages with microfinance, business training and better access to simple equipment for the processing and packaging of raw products.

From the above it is clear that the commercialization of sustainably grown products delivers really important impacts from agroforestry and multifunctional agriculture (Figure 5). However,

we have to recognize that commercialization that can also pose great risks affecting the success or failure of the overall initiative. One study has found that bottom-up community initiatives like those described here have the greatest chance of being 'winners', although if the companies involved recognize the importance of buying raw products from local smallholder producers, top-down commercialization can also be effective (Wynberg *et al.* 2003).

FIGURE 5. DIAGRAMMATIC REPRESENTATION OF HOW THE THREE STEPS TO CLOSE THE YIELD GAP IMPACT ON FOOD SECURITY, POVERTY AND LIVELIHOODS (SUSTAINABLE INTENSIFICATION)



One important and exciting thing about the Cameroon project has been the wide range of positive livelihood impacts that the farmers are saying have truly transformed their lives (Leakey and Asaah, 2013). These require further quantification and verification, but include: substantially increased income, new employment opportunities, improved nutrition, improved health from

potable water and better diets, and the ability to spend money on children's schooling, home improvements, wells, etc. Significantly, one of the outcomes mentioned by young people in the participating communities is that this now means that they can see a future for themselves if they remain in the village rather than feeling that they have to migrate to towns and cities for a better life. In addition, women have indicated that improved infrastructure (wells, roads, etc.) has reduced the drudgery in their lives as a result of not having to collect water from rivers and carry farm produce from remote farms. These benefits, like the mechanical processing of food crops, have meant that they had more time to look after their families and engage in farming or other income generating activities.

It is encouraging that the levels of income generation achieved in Cameroon, albeit on a very small scale, exceed those proposed in the Millennium Development Goals. This and the other impacts presented here strongly suggest that by promoting self-sufficiency through the empowerment of individuals and community groups through the provision of new skills in agroforestry, tree domestication, food production and processing, community development, and microfinance, it is possible for communities to climb the entrepreneurial ladder out of poverty, malnutrition, and hunger. What is needed now is to disseminate this approach to millions of other poor people in Africa and other tropical countries.

To conclude, through the integration of rural development activities, farmers in Cameroon are intensifying their farming systems in ways that are environmentally, socially and economically more sustainable, while people in local villages and small towns are developing cottage industries and engaging more in marketing and trade. The consequence of this has been the start of the climb out of poverty and entry into the cash economy. This relationship between enhanced farm production and urban life is important for the rural economy as it is an example of farm production being the 'engine of growth'. This is perhaps the start of a new approach to rural development in the tropics – one that perhaps replicates what happened thousands of years ago in the Near East and Europe as cereals and other staple food crops were domesticated and brought into cultivation. Interestingly, Diamond (1997) has credited the domestication of food crops with the advance of western civilization. Recognizing this power of crop domestication, Leakey (2012a/d) has called for a 'new wave of domestication' to benefit people in developing countries who did not greatly benefit from the first wave. In this regard, one interesting development in recent years has been the involvement of a few multinational companies in Public-Private Partnerships with rural communities engaged in production of agroforestry products in tropical countries (Jamnadass *et al.* 2011; Leakey, 2012a). Although associated with risks, this also offers great opportunities for the future development of agroforestry tree crops if the strategies and practices can be developed appropriately.

SUSTAINABLE INTENSIFICATION

Currently, there is great interest internationally in seeking 'sustainable intensification' (Garnett and Godfray, 2012; Garnett *et al.* 2013). This paper presenting 12 principles for achieving both better and more food from mature perennial agro-ecosystems seeks to contribute to this debate and illustrate how the domestication of indigenous trees producing high value products, such as traditional foods and medicines, can be a catalyst for sustainable and integrated rural development. This paper also emphasises that an important strategy within this approach to sustainable intensification is the implementation of steps to restore productivity to degraded land and close the Yield Gap and meet the needs of a growing human population without the need for further deforestation (Figure 5; Leakey, 2012a). Clearly, the challenge for the future is to scale up the application of the principles outlined here to have meaningful impact on national, regional and global scales. A key to achieving this will be the attainment of political will. Towards this end, the IAASTD (McIntyre *et al.* 2009) placed a need for greater emphasis on:-

- Integrated approaches to land use management involving participatory approaches to planning and implementation
- Less exploitative approach to natural resources, especially soils and water, and a lower dependence on inorganic inputs and fossil energy
- Good husbandry to support agro-ecosystem health, restoration of degraded land and the reduction of the 'Yield Gap'.
- Increased involvement of local user groups in actions to improve natural resources management.
- Diversification of agriculture for improved soil amelioration, pest and disease control, and new marketable products.
- The domestication of new nutritious and marketable crops from local species, especially trees, to diversify diets and the local economy.
- Enhancement of rural livelihoods by meeting the needs of local people and supporting culture and tradition.
- Better integration of agricultural sectors, government departments and institutions, communities, and stakeholders to overcome "disconnects" in policy and practice.
- Public–private partnerships involving diverse stakeholder groups at the local level to support sustainable production, and in-country processing and value-adding.
- There is strong accord between these pointers to a better future for agriculture from IAASTD and the principles outlined in this paper.

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