# Converting 'trade-offs' to 'trade-ons' for greatly enhanced food security in Africa: multiple environmental, economic and social benefits from 'socially modified crops'

**Roger R. B. Leakey**

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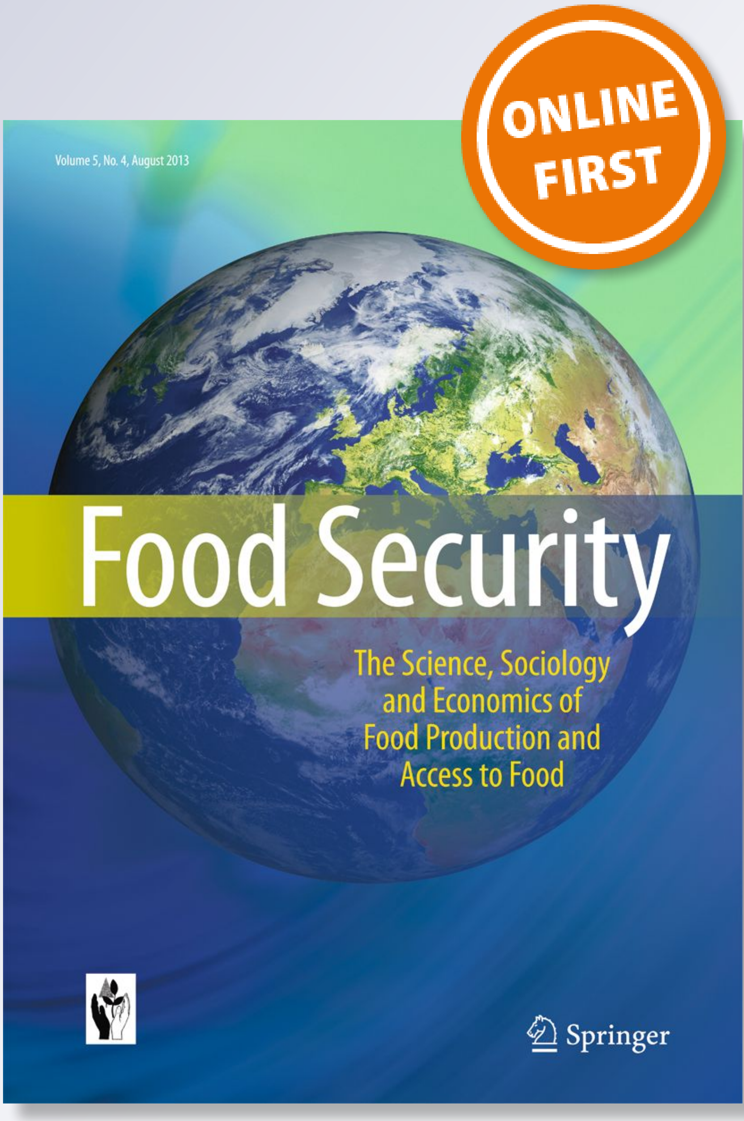


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REVIEW

# Converting 'trade-offs' to 'trade-ons' for greatly enhanced food security in Africa: multiple environmental, economic and social benefits from 'socially modified crops'

Roger R. B. Leakey[1]

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**Abstract**

To address the issues of food insecurity within the context of land degradation, extreme poverty and social deprivation, this review seeks first to understand the main constraints to food production on smallholder farms in Africa. It then proposes a highly-adaptable, yet generic, 3-step solution aimed at reversing the downward spiral which traps subsistence farmers in hunger and poverty. This has been found to be effective in greatly increasing the yields of staple food crops and reducing the 'yield gap'. This solution includes the restoration of soil fertility and ecological functions, as well as the cultivation, domestication and commercialization of traditionally-important, highly nutritious, indigenous food products for income generation and business development. A participatory approach involving capacity building at the community-level, leads to the development of 'socially modified crops' which deliver multiple environmental, social and economic benefits, suggesting that increased agricultural production does not have to be detrimental to biodiversity, to agroecological function, and/or to climate change. These are outcomes unattainable by attempting to raise crop yields using conventional crop breeding or genetic modification. Likewise, the livelihoods of smallholder farmers can be released from the constraints creating spatial trade-offs between subsistence agriculture and (i) international policies and (ii) globalized trade.

**Keywords** Agroecology · Agroforestry · Domestication · Income generation · Land restoration · Multifunctionality · Socially modified crops

## 1 Introduction

A practical, socially- and environmentally-appropriate, and effective solution to Africa's food and nutritional security, land degradation and poverty problems, has eluded everyone for over 100 years. Early colonials did not understand either the biophysical or social situations that they were trying to improve (Maathai 2009). Subsequently, the industrializing countries of the North saw opportunities for wealth generation growing out of trade and new manufacturing, based on cheap commodity imports. The Green Revolution then introduced globally the concept of high-input monocultures of exotic staple food crops and mechanization. Trees were considered a hindrance to be removed. This series of events failed to recognize three important points, that trees are: (i) crucial for the retention of soil fertility and ecological health of fragile soils; (ii) important for the biocontrol of pests and diseases in ecosystems adapted to their high biodiversity, and very importantly, (iii) they are the source of traditionally- and culturally-important food and non-food products greatly appreciated by local peoples (Leakey 2012a). This is especially important in Africa, where trees are central environmental and social keystones for sustainability. The negative impacts on ecological sustainability of this intensive foreign approach to agriculture have then been exacerbated by expecting millions of smallholder farmers living on the brink of the cash economy to purchase the essential technical inputs. Basically, this has not happened and consequently, the soils have become increasingly degraded and infertile – trapping farming households in hunger and poverty (Cribb 2010). The severity of the global food crisis, and its associated social and economic problems, would probably not be of worldwide concern if conventional approaches to income generation, such as the cultivation of cash crops, were sufficient to meet the needs

✉ Roger R. B. Leakey
rogerleakey@btinternet.com

[1] International Tree Foundation, 256 Banbury Road, Oxford, England OX2 7DE

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of subsistence farmers. However, those farmers who do manage to grow and market commodity cash crops like cocoa, coffee, tea, rubber, still struggle to earn enough. This is due in large part to overseas price regulation; which is to some extent offset by 'Fair-trade' schemes which do make some difference to farmer income (Le Mare 2008).

Despite the above, the Green Revolution has had many global benefits (Everson and Gollin 2003) and has greatly increased the production of food in industrialized, and some transitional, countries. Interestingly, Norman Borlaug, the father of the Green Revolution, only saw it as "a temporary solution, a breathing space, in man's war against hunger and deprivation" (Borlaug 1970), thus it seems very appropriate that we now look to make further progress.

Agriculture is often said to be the 'engine of economic growth' (Gemmell et al. 2000; Tiffin and Irz 2006). So, when many African countries are still among the poorest is it appropriate to ask if this maxim can be turned on its head, by saying that the problems of tropical agriculture are the reason for the lag in economic growth in many African countries? We clearly live in a divided world of rich and very poor. This is illustrated by the global median *per capita* income per year: reported to be between US$850 and $2630 (US$2–7 per day), depending on how it is calculated (Gallup 2014). When calculated nationally, all African countries fall below the overall median (Fig. 1). With about 1.3 billion people trapped on degrading agricultural land (UNCCD 2017) typically engaged in subsistence agriculture and suffering from food and nutritional insecurity, it seems that the pursuit of modern intensive approaches to farming, conventional in temperate environments, has dramatically failed the people of tropical and subtropical Africa. The outcome of this failure is the economically- and socially-divided world of rich and ultra-poor, and a planet creaking environmentally from the over-exploitation of natural resources; loss of biodiversity; pollution and waste, and land degradation so severe that crops barely meet the food needs of nearly half the people; even in good years. On top of this, there is growing evidence that all these impacts combine to form atmospheric changes which are negatively impacting life on earth.

Great efforts have been made over the last 70 years to address these worrying outcomes of population growth and industrial expansion, recognizing the need for more sustainable approaches to agriculture. Unfortunately, one common message has prevailed and been accepted. It is that there are 'trade-offs' between enhanced food production and its impacts on the environment (including climate change) and on the biodiversity needed for healthy agroecosystems. But is this inevitable?

This review focuses on how to achieve multifunctionality at the farm level by resolving issues resulting from trade-offs between intensive monocultures, the environment and the livelihoods of subsistence farmers. In particular it examines the agroecological and socio-economic benefits from new tree crops cultivated in mixed cropping systems by smallholder farmers in the tropics and sub-tropics to deliver more sustainable agriculture with enhanced agroecology functions, environmental rehabilitation, greater productivity and income generation (Leakey 2017c). This does not exclude the use of modern conventional technologies.

## 2 Understanding the problem

To examine the impact of agricultural science and technology on global food production, an international initiative – International Assessment of Agricultural Science and Technology for Development - did an evaluation of 297 reported consequences of modern agricultural practices (Leakey et al. 2009). These were scored −5 to +5 and it was found that 64% were positive and 36% were negative in terms of production, delivery of ecosystem services, farmer livelihoods and regulatory processes (Fig. 2). A set of 10 lessons and challenges were then drawn from these findings. Subsequently, an analysis was

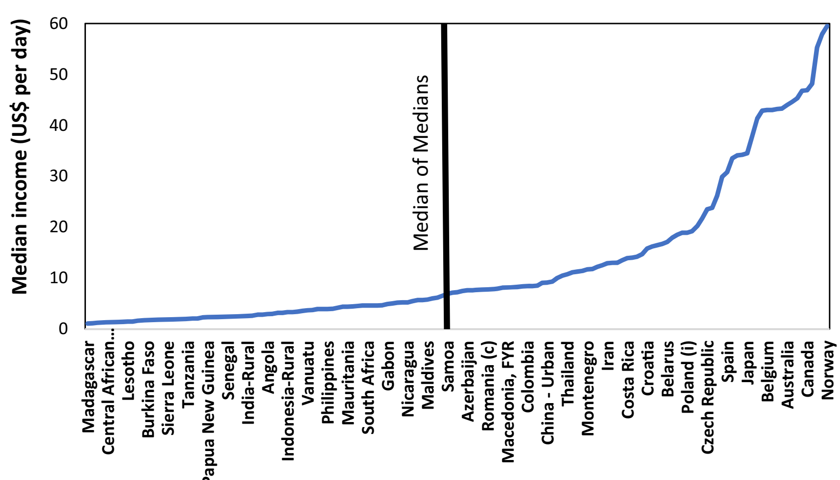


**Fig. 1** The median income per day (adjusted for purchasing power parity) of countries across the world in US$ per day (Diofasi and Birdsall 2016). N.B. All African countries fall below the median of these medians

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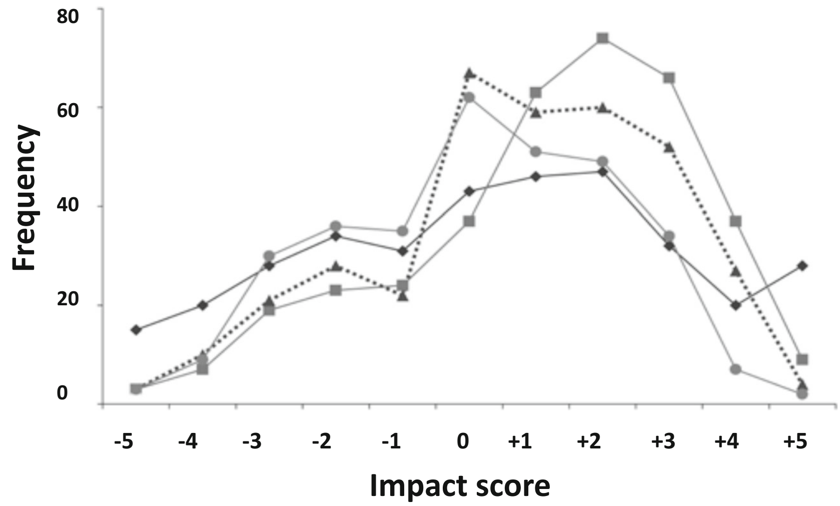


**Fig. 2** Frequency distribution of 'impact scores' for 297 reported consequences across four areas of agricultural science and technology (♦ = agricultural productivity, production factors and consumption, ■ = Sustainability through integrated technologies and the delivery of ecosystem services and public goods, ▲ = livelihoods, capacity strengthening and empowerment, ● = relationships in coordination and regulatory processes among multiple stakeholders) (Leakey et al. 2009)

made of the constraints to smallholder agricultural production in the tropics and sub-tropics. This analysis identified a complex interacting set of environmental, social and economic factors forming a downwards spiralling 'Cycle of land degradation and social deprivation' arising from an inability to address soil infertility (Fig. 3). Driving this cycle is the need for food security and a better life. This has typically led to deforestation, overgrazing and to soil degradation; outcomes often exacerbated by profit-seeking external entrepreneurs. This exploitation of natural resources in turn generally leads to the loss of biodiversity, the breakdown of agroecosystem functions and the loss of soil fertility, with serious consequences of declining crop yields, hunger and declining livelihoods. These, of course, exacerbate the desires of farming households for food security and consequently return the spiral to the top of the cycle. These impacts affect hundreds of millions of poor smallholder farmers seriously. Commonly, the proposed solution is to seek improvements in the yield potential of our crops. However, when the problem is 'actual yield' and not 'potential yield' this is flawed logic. Thus, contrary to this 'knee-jerk' reaction to low yield, the only effective solution is to reverse the cycle of land degradation and social deprivation. This involves better crop husbandry and income generation (Leakey 2012a, 2013) – the subject of this review.

Lessons learned from the above historical evaluation (Table 1) have led to the presentation of a set of process-oriented targets for more sustainable agriculture in the tropics and sub-tropics (Table 2); together with some principles for use to address them (Table 3). These targets and principles recognize the importance of addressing food and nutritional insecurity in a holistic way that also takes into account the poverty of subsistence farmers, their social situation and land degradation. They are cross-cutting (Table 4) and encourage a more integrated approach to addressing the complex range of environmental, social and economic constraints within the rural economy which limit agricultural production (Fig. 1). Likewise, these targets and principles cut across the outcome-oriented Sustainable Development Goals and the

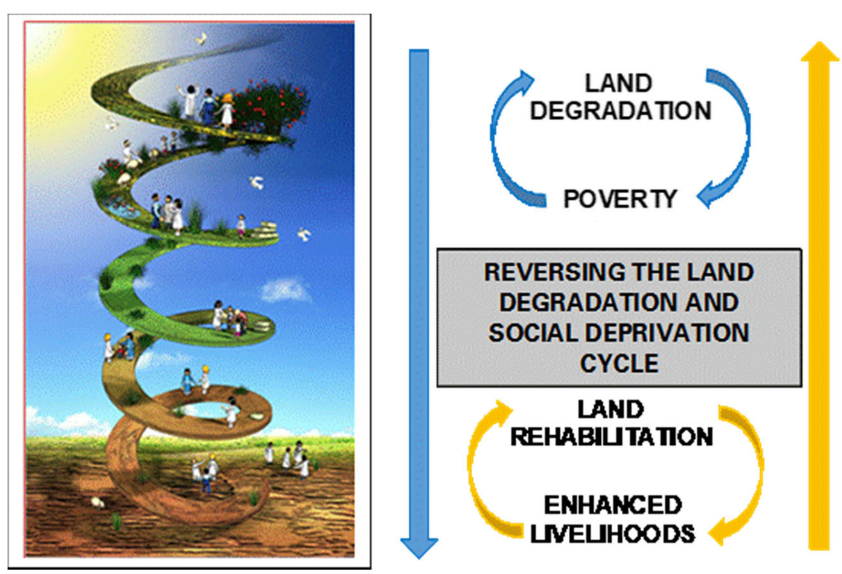


**Fig. 3** Multifunctional Agriculture involves reversing the cycle of land degradation and its associated social deprivation issues. (Leakey 2017e)

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**Table 1** Lessons from historical evaluation of Agricultural Knowledge, Science and Technology (Leakey et al. 2009)

| No | Lessons from historical evaluation of Agricultural Knowledge, Science and Technology |
|---|---|
| 1 | Excessive reliance on the draw-down of natural capital |
| 2 | R&D has failed to address the "yield gap" |
| 3 | R&D has largely ignored traditional production systems for wild resources |
| 4 | R&D has failed to fully address the needs of poor people |
| 5 | Malnutrition and associated poor human health are still widespread |
| 6 | Intensive farming is frequently promoted and implemented unsustainably |
| 7 | Agricultural governance and institutions have focused on producing individual commodities |
| 8 | Agricultural activities have been very isolated from non-agricultural activities in the rural landscape |
| 9 | Agricultural science and technology has suffered from poor linkages among its stakeholders and actors |
| 10 | For decades 'Globalization' has been isolated from local communities at the 'grassroots' |

prior Millennium Development Goals. Other authors have listed different, but related, key policy requirements for the up-scaling of the sustainable intensification of agriculture (Pretty et al. 2011; Pretty and Bharucha 2014) and the premises for sustainable intensification (Garnett et al. 2013).

## 3 Going forwards

From a global perspective, there have been many international calls for new approaches to address the environmental, social, and economic problems associated with agriculture (Millennium Ecosystem Assessment 2005; Global Environmental Outlook 2007; Comprehensive Assessment of Water Management in Agriculture 2007; International Assessment of Agricultural Science and Technology for Development 2009; Royal Society 2009; United Nations Convention to Combat Deforestation 2017; World Economic Forum 2017) especially in Developing Countries. These have stressed that 'business as usual' is not appropriate, without indicating how sustainable agriculture can actually be achieved. In part, at least, this reflects much resistance to change within industrialized countries with many powerful agribusiness and academic communities interested in the *status quo*. Consequently, there is no consensus on how to go forwards despite clear Sustainable Development Goals (http://www.un.org/sustainabledevelopment/sustainable-development-goals/). As mentioned earlier, this exposes the very different context of farming in industrialized and non-industrialized countries, and their very different impacts on the lives of both rural and urban populations. This suggests that the strategies for agricultural development under these two situations should be very different – especially when the farms are also in the very different physical, social and economic environments of Developing and Industrialized Countries. It is also relevant to recognize that farms in these two regions differ greatly in size, and that typically there is a negative relationship between farm size and efficiency of production (Place and Hazell 1993; Deininger and Castagnini 2006).

This review presents an often overlooked, but positive, perspective on the future of farming; one in which agriculture can perhaps again be seen as the 'engine of economic growth' and the 'promoter of social justice', due to its positive impacts on the environment and the rural economy. It is based on the

**Table 2** Eleven process-oriented targets for action to transform the productivity and sustainability of tropical and sub-tropical agriculture and associated rural development (see: Leakey and Prabhu 2017)

| No. | Target |
|---|---|
| 1 | Recognize need for different approaches – both agronomic and economic |
| 2 | Restore and maintain soil fertility for sustained high-level production. |
| 3 | Restore and maintain agroecological processes for sustained and resilient production. |
| 4 | Domesticate and improve indigenous species as new crops for: (i) better nutrition and (ii) income generation |
| 5 | Close the Yield Gap by addressing local supply side and livelihood problems |
| 6 | Provide training in rural communities to enhance their capacity to implement technologies relevant to Sustainable Intensification |
| 7 | Achieve energy security without environmental damage. |
| 8 | Reduce and eliminate waste. |
| 9 | Promote integrated livestock management in drylands and animal welfare. |
| 10 | Maintain landscape functions (such as watershed protection, carbon sequestration, access to institutions and markets, etc). |
| 11 | Maintain global functions (such as the mitigation of climate change and wildlife conservation, access to policy makers, etc). |

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**Table 3** Twelve principles for the delivery of Multifunctional Agriculture by agroforestry (modified from: Leakey 2014b)

| No. | Principle |
|---|---|
| 1 | Understand and solve underlying problems: The Big Picture |
| 2 | Ask and don't tell farmers what they need |
| 3 | Skills and understanding are better incentives for farmers to engage, than money |
| 4 | Build on local culture, tradition and markets |
| 5 | Use appropriate technology, encourage diversity and indigenous perennial species |
| 6 | Encourage species and genetic diversity |
| 7 | Encourage gender/age equity |
| 8 | Encourage farmer-to-farmer dissemination |
| 9 | Promote new business and employment opportunities |
| 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 |

findings of 'Diagnosis & Design' exercises (Raintree 1987), and Participatory Rural Appraisal (Franzel et al. 1996, 2008).

### 3.1 Addressing food insecurity, land degradation and poverty

The lessons learned from a historical review of agriculture (Table 1) point to a failure to adequately appreciate a series of interacting environmental, social and economic factors which are driving the downward spiralling 'Cycle of land degradation and social deprivation' (Leakey 2010, 2012a, 2013, 2017a). The consequent Yield Gap in staple food crops is the major issue causing food insecurity and is the manifestation of the complex problem and is affected by soil type, the climate and management practices (Sileshi et al. 2010). In Africa, Yield gaps are commonly found in most crops, especially the widely grown cereals. For example, maize yields across the continent average about 1.5 t $ha^{-1}$ despite potential yields of modern varieties being around 7 t $ha^{-1}$ (Sebastian 2014). Closing this gap would result in about a 5- to 6-fold increase in cereal production; a gain well above that foreseen as necessary for self-sufficiency in Sub-Saharan Africa by 2050 (van Ittersum et al. 2016).

To reverse the Cycle means that instead of 'land degradation driving poverty and poverty driving further land degradation' we make 'land rehabilitation drive poverty reduction and poverty reduction drive further land rehabilitation' (Fig. 3). This involves three steps.

#### 3.1.1 Step 1, Restoration of soil fertility and health

To do this we must recognize the extreme poverty of subsistence farmers and start with a very low-cost approach to improving soil fertility by better crop husbandry. This has been a

**Table 4** Relationships between 'Lessons from the past' and the 'Targets' and 'Principles' for how to achieve more sustainable tropical/sub-tropical agriculture

| | Lessons from historical analysis | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Principles** | 1 | 7 | 2 | 5 | 3 | 6 | 4 | 8 | 9 | 10 |
| 1 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| 2 | | | √ | | √ | √ | √ | √ | √ | √ |
| 3 | | | √ | | √ | √ | √ | √ | √ | √ |
| 4 | | | √ | √ | √ | √ | √ | √ | √ | √ |
| 5 | | | | √ | √ | √ | √ | √ | √ | √ |
| 6 | | | | √ | √ | √ | √ | √ | √ | √ |
| 7 | | | | | | | | √ | √ | √ |
| 8 | | | √ | | √ | | | √ | √ | √ |
| 9 | | | | | | | √ | √ | √ | √ |
| 10 | √ | √ | √ | √ | | √ | √ | √ | √ | √ |
| 11 | √ | √ | √ | √ | | √ | √ | √ | √ | √ |
| 12 | √ | √ | √ | √ | | √ | √ | √ | √ | √ |

| | Lessons from historical analysis | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Targets** | 6 | 3 | 5 | 2 | 4 | 8 | 7 | 10 | 9 | 1 |
| 1 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| 2 | | | | √ | √ | | | | √ | √ |
| 3 | | | | √ | √ | | | | √ | √ |
| 4 | | √ | √ | √ | √ | √ | √ | √ | √ | |
| 5 | √ | | | √ | √ | | | | √ | |
| 6 | | √ | √ | √ | √ | √ | | √ | √ | |
| 7 | | | | | √ | √ | | √ | √ | √ |
| 8 | | | | | | √ | √ | √ | √ | |
| 9 | | | | | | | √ | | √ | |
| 10 | | | | | | | √ | √ | √ | √ |
| 11 | | | | | | | √ | √ | √ | √ |

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focus of agroforestry research for over 30 years and is now well developed (Sanchez 2002; Sileshi et al. 2008, 2014). It involves the growth of nitrogen fixing trees and shrubs (so-called 'fertilizer trees') to replenish soil nitrogen and start the process of rebuilding the below- and above-ground agroecological functions (Khan et al. 2006; Garrity et al. 2010; Sileshi et al. 2014; Garbach et al. 2014; Lavelle et al. 2014; Perfecto et al. 2014; Leakey 2014a, 2017a). Below ground, these functions include changes to the soil structure as well as its organic matter content, which has profound effects on soil health and water use efficiency (Sileshi et al. 2014). Programmes of this sort can be effectively implemented using participatory processes in rural communities (Ndungu and Boland 1994) and can have beneficial effects on food security and income generation (Kangmennaeng et al. 2017).

An agroecological approach typically diversifies a farming system by establishing a range of different crops in different configurations and densities. These crops represent the planned biodiversity. When some of these crops are trees they create niches above- and below-ground to be colonized by other wild organisms – the 'unplanned biodiversity'. It is the complex food chains and life cycles of these organisms that are central to the achievement of sustainability (Leakey 2014a). They, together with nutrient, carbon and water cycling, are the key processes that ensure the proper functioning of maturing agroecosystems. This process has been proposed as Step 1 in a 3-stepped approach to closing the Yield Gap (Leakey 2012a, 2013). Other approaches to organic farming, such as the use of mulches and manures, can also have complementary beneficial impacts (Badgley et al. 2006). However, evidence indicates that manures cannot be produced in sufficient quantity to meet the complete needs of the cropping systems (Mafongoya et al. 2006).

There have been many calls for an agroecological approach to address the problems of unsustainable agriculture (Pretty 2006; Holt-Giménez and Altieri 2013). Highly desirable as this is, it is nevertheless not the complete solution as even with better crop husbandry there will still be a yield gap (around 50%) due to soil deficiencies in other major and minor nutrients. These nutrients cannot be replenished biologically, and so have to be addressed by the use of inorganic minerals – most practically by the use of artificial fertilizers (Sileshi et al. 2010). However, as we have seen, poverty-stricken smallholder farmers do not have access to these, so the next step to closing the Yield Gap has to be income generation (Leakey 2010, 2012a, 2013).

### 3.1.2 Step 2, income generation with new cash crops

When farmers in Cameroon were asked what they would like to be able to grow to generate income the response was unexpected (Franzel et al. 1996). Overwhelmingly, they said that they would like to cultivate the indigenous tree species that produce the traditionally- and culturally-important food and non-food products that local communities used to gather from natural forests and woodlands when they existed close-by. Around the world there are tens of thousands of useful species producing edible and medicinal products well known to local people, ethnobotanists and ethnopharmacologists (Abbiw 1990; Cunningham 2001). Many of these could be cultivated (Leakey 1999). Currently, only about 0.05% of the edible species have been domesticated as crops (Leakey and Tomich 1999), many being described by foreigners as 'famine foods' although this is a misnomer, as very many of these products are highly appreciated and marketed locally (Leakey and Newton 1994; Leakey 1999; Leakey 2017a, 2017b, 2017c, 2017d, 2017e). The programme in Cameroon has led to similar initiatives around the tropics, with farmers typically selecting indigenous fruits and nuts as their top priority species for cultivation (Franzel et al. 2008). Currently, over fifty indigenous fruit and nut species are in the process of domestication worldwide (Leakey et al. 2012). Importantly, the foods these species produce are also very much more nutritious than staple food crops and so have many health benefits (Leakey 1999; Powell et al. 2015).

Recent research in Cameroon has examined the suggestion that there may be some social stigma associated with the consumption of indigenous fruits, rather than popular exotics like mango, avocado, citrus, etc. However, the study found that there is no stigma in the local population against their use, even in periurban communities, and that they are recognized locally as having great potential to enrich and fortify diets. (Ngome 2017; Ngome et al. 2017). Similarly, indigenous foods are widely used by urban dwellers in Uganda (Mollee et al. 2017). However, a different situation has been reported in Kenya (Keding et al. 2017) where despite 80% of women having low vitamin A and C intake, wild fruits were viewed as 'poor man's food'. This contrasts with the Sahel, humid west and central Africa, and the Miombo woodlands of southern Africa, and perhaps reflects the relative lack of desirable indigenous fruits in Kenya, and their low place in local ethnobotany.

Step 2 in the 3-stepped approach to closing the 'Yield gap' and reversing the 'Cycle of land degradation and social deprivation', is therefore to rebuild the resource of traditionally-important forest species that produce useful non-timber forest products. In Cameroon, this domestication step was initiated in participatory mode to help farmers to cultivate the indigenous trees producing useful food and non-food products in 1994 (Leakey 2012a). Since then it has been both up-scaled and out-scaled as a community-based approach to crop domestication (Tchoundjeu et al. 2002, 2006, 2010; Asaah et al. 2011; Leakey et al. 2003; Degrande et al. 2012; Leakey 2014c). In parallel, a multi- and trans-disciplinary research programme was established to determine the appropriate strategies and techniques. This

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research made rapid progress over the first two decades (Leakey et al. 2012) and continues to do so. It is now a component of two CGIAR Flagship Programmes (http://www.cgiar.org/about-us/our-programs/) as well as many smaller research projects implemented by universities and research institutes around the world.

The domestication strategy developed to deliver this participatory programme was to apply a horticultural approach to rapidly developing cultivars from individual wild trees which were phenotypically superior (Leakey and Simons 1997; Leakey and Akinnifesi 2008). These elite trees were either already known to local people, or easily identified by simple characterization of the variation in fruit or kernel traits (Leakey et al. 2000). These trees were then propagated vegetatively (Leakey 2014d) in village nurseries using non-mist, poly-propagators made from local materials (Leakey et al. 1990), without the need for electricity or running water. Phenotypic characterization was used to identify useful traits. These were found to vary 3- and 10-fold between individual trees (e.g. Waruhiu et al. 2004), and desirable traits like size and flavour were seldom well correlated. Consequently, the selection of elite individual trees with the combination of a number different traits relating to a specific market, or industry, required the identification of an 'ideotype' (Leakey and Page 2006). In some species, it is possible to identify trees matching ideotypes for fruits, as well as for kernels, or for some biochemical ingredient specific to their nutritional and/or medicinal properties. Importantly, it was also found that each village population contains most of the available variation (de Smedt et al. 2011; Pauku et al. 2010). Using molecular markers, the level of this site by site intraspecific phenotypic variation was found to exceed 85% (Pauku et al. 2010). This means that each village could make its own selections and that this village-based, decentralized approach to domestication is an appropriate strategy that maximises production benefits to participating communities, while minimizing the losses of genetic diversity that are often ascribed to domestication (Leakey 2017a). Under certain circumstances there can be tree ownership issues regarding land tenure and communal rights (Schreckenberg et al. 2002; Gyau et al. 2014), but this has not been a severe problem.

To implement this strategy at the practical level, participatory domestication hubs were developed at the community level in Cameroon (Tchoundjeu et al. 2002, 2006, 2010; Asaah et al. 2011). This, as described later in more detail, was based on a strategy of integrated rural development focusing on the provision of farmer training in a wide range of technical and social skills (Degrande et al. 2012). This capacity building exercise aims to provide individual farmers with the necessary knowledge and understanding to create village tree nurseries, develop agroforestry systems that meet their own needs, domesticate their own cultivars and market their own products (Asaah et al. 2011; Leakey and Asaah 2013). This empowers individual households to become self-sufficient for food and other day-to-day needs, as well as generating income for investment in local facilities such as wells or piped water, and to expand into other enterprises such as livestock production. At the community level, training provides access to small-scale loans, enhances capacity in community organization and finance management, communal infrastructure development, and marketing (Leakey 2017a). It is this socially-oriented, community-based approach to domestication that distinguishes these new crops as 'socially modified organisms' (Leakey 2017b). Currently these emerging crops are exclusively wild woody perennials well known to local communities, but little known to science until the advent of this programme of research (Leakey 2012a). Their domestication and commercialization raise issues in terms of the protection of intellectual and biological property (see section 3.1.4).

#### 3.1.3 Step 3, Commercialization of new crop products

Following domestication, the next step involves the marketing of the new crop products. Traditionally many of the non-timber forest products gathered from the wild have been sold by women in local informal markets on roadsides, or at street corners. A few of the species have also been traded regionally. The important point here is that local people are aware of the desirability and usefulness of these products which have recognized economic value. Interestingly, this local retail market recognizes the tree-to-tree variation mentioned above and so fruits with desirable combinations of traits fetch a very much higher price. In the case of safou (*Dacryodes edulis*) this price differential can be more than 35-fold for an individual fruit in a single marketplace. Unfortunately, in contrast, the prices in the regional wholesale trade of the same fruits do not recognize the variation as these bulk samples contain the full range of tree-to-tree variation found in a wild population (Waruhiu et al. 2004). Thus, perhaps it is only when the wholesale bulk sample can contain fruits from elite cultivars, that the wholesale price will reflect the quality of the product. This illustrates that for products to progress up the value chain it is essential that the product increases in uniformity, in the regularity/reliability of supply. These are both outcomes of the domestication process and so provide further incentive for farmers to produce cultivars (Leakey and van Damme 2014).

Another big opportunity for the commercialization of these products lies in their processing and packaging for the extension of shelf life (Leakey and van Damme 2014). While some nuts, kernels and leafy vegetables are often traditionally processed (Todou et al. 2017; Ngadze et al. 2017) many of the fruits have a very short shelf life (Leakey 2012a). Thus, they are only amenable to local marketing and their nutritional benefits are only available to the

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local population during the fruiting season. It is evident therefore, that simple value-adding processes could have very significant benefits. This work is in its infancy for the key species being domesticated but is currently an initiative being picked up by local women's groups (e.g. Manyu Women's Multipurpose Cooperative in Cameroon). Likewise, the activities of the Rural Resource Centres in Cameroon are also stimulating entrepreneurial women in the community to process staple food products, such as cassava, and this is generating significant income (Leakey and Asaah 2013). Additionally, the local interest in processing is also stimulating new business by metal-workers who are developing simple equipment for drying fruits, cracking nuts, extracting kernel oil, and grinding a range of products (Asaah et al. 2011; Mbosso et al. 2015). Likewise, in southern Africa, the commercialization pathway has been found to be important with specific regard to the domestication of indigenous fruits and kernels of Marula (*Sclerocarya birrea*). This study found that there could be both negative and positive impacts of commercialization on social and cultural elements of community life: positive when control of the commercialization was at the local level, but negative when regulated externally (Wynberg et al. 2002; Shackleton et al. 2009) without regard to the rights of producers (Lombard and Leakey 2010).

In addition to what is happening at the local level, there is also some international interest in some of these products. For example, there are now hundreds of baobab products (*Adansonia digitata*) on the shelves of stores in Europe; and new processed products from *Allanblackia* species are being marketed as margarine in Sweden (Jamnadass et al. 2010, 2014). For these international initiatives to have big economic impact in Africa they should, however, be processed in the country of origin. This will require progressive and innovative industrial partners with a different mindset.

#### 3.1.4 Legal issues

Several unaddressed issues can be raised here. Firstly, non-timber forest products are common-property forest resources which are not included in national or international trade/production statistics, but this should change as they become private property farm products – now described as 'Agroforestry Tree Products' (AFTPs – see Simons and Leakey 2004; Leakey 2012b). Secondly, this name change would also have important policy implications, as in many countries the marketing of forest products is illegal, in an effort to reduce deforestation. Unfortunately, these laws are a disincentive for farmers to diversify their cropping systems with local species (Foundjem-Tita et al. 2012). The categorization of these products as farm crops would remove this disincentive. Thirdly, international law does not adequately recognize the rights of farmers over their commercial innovations, especially as they apply to poor smallholder farmers totally unable to effect Plant Breeders Rights over their intellectual property. Until this is changed, some steps to provide some interim protection have been suggested by Lombard and Leakey (2010) and Santilli (2015).

#### 3.1.5 Multidisciplinarity

From all the above, it is clear that reversing the Cycle of land degradation and social deprivation requires a multidisciplinary approach with a combination of interventions that together form an integrated package that greatly increases food security at the household level by closing the Yield gap. It's clear that this package also has beneficial impacts on nutrition, poverty alleviation and a number of the important environmental factors that contribute to the stagnation of agriculture in Africa (Leakey 2012a; Leakey and Prabhu 2017). To elaborate further on this point:-

- The biological nitrogen fixation from Step 1 replenishes soil nitrogen and so provides a crucial boost to food security and calorie production for relief from the hunger caused by declining staple crop yields. This yield enhancement equates to the application of the recommended dose of artificial fertilizer (Jama et al. 2017). These 'fertilizer' trees also produce wood fuel, bee and livestock fodder as well as enhancing soil organic matter and agrobiodiversity, while reducing susceptibility to erosion and improving soil structure and water retention. Nevertheless, smallholder farmers remain in subsistence agriculture. Importantly, however, the higher yields mean that the area of the farm (typically about 2 ha in total) dedicated to staple foods can be reduced, so freeing up space for other enterprises including conventional cash crops and the new indigenous tree crops: the socially modified organisms (SMOs).
- It is the SMOs developed by Step 2 and marketed in Step 3 that restore a declining resource of indigenous tree species producing useful, marketable and highly nutritious products, creating a new template for tropical and sub-tropical agricultural production that motivates subsistence farmers to improve their lot in life and develop new horizons, based on better access to traditionally-important foods and locally useful non-foods.
- Community engagement and capacity building empowers the community, especially women and youths, to become self-sufficient, and to see a route out of poverty (Schreckenberg et al. 2006) – with a vision for the future. Additional benefits are lower stress, better and more diversified diet based on local cuisine (Baxter 2017) and improved health, more opportunities for advancement in the rural economy and in society. The recent discovery that traditional African diets confer health advantages over

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modern processed foods due to their effects on the gut microbiome (Schnorr et al. 2014), add further impetus to the tree domestication initiative.

- Environmentally, the diversification of the farming system with these new tree crops, enhances biological diversity above- and below-ground for improved ecological functions giving greater resilience to pests and diseases (Leakey 2014a) as well as enhanced carbon sequestration and further access to wood fuel. The transition to more sustainable and wild-life friendly farming systems should reduce the need to clear forests and woodlands.
- The income generation from the sale of tree seedlings from village nurseries and the marketing of the raw and processed products (AFTPs) from new SMO cultivars based on ideotypes matching the needs of local markets and new cottage industries, allows households to invest in local infrastructure and new enterprises (livestock, honey, fish farming, medicinal products, post-harvest processing and value-adding, etc.), access to education and health, access to markets and market information via mobile phones and transport, etc., linking producer groups to traders and so creating awareness of supply and demand (Degrande et al. 2014).
- New cottage industries further increase the scope for income generation, with the added advantage that the wider public gains access to nutritious foods out of season. However, there is a downside, access to income and its associated wealth exposes people to convenience foods as alternatives to natural products. This can increase the risk of obesity.

Based on the above, Leakey (2012a, 2013, 2017a) has proposed a conceptual framework for multifunctional agriculture (Fig. 4) in support of the approach proposed by the reports of International Assessment of Agricultural Science, Knowledge and Technology for Development (IAASTD 2009; Kiers et al. 2008).

## 4 Supporting the social dimension

Innovation often demands sophisticated integration with local partners so that technology is built into capacity building and appropriate networks (Kiers et al. 2008). Earlier, Rural Resource Centres (RRCs) were described as grassroot, farmer-centred hubs to implement a participatory domestication programme for the social modification of indigenous trees as new crops. Here we examine how these Centres were developed as a decentralised social network (Degrande et al. 2015; Franzel et al. 2015). An understanding of this is needed if the concept of socially modified crops is to be adopted more widely. RRCs are registered as an NGO, aimed at providing extension services to local communities in ways that nurture

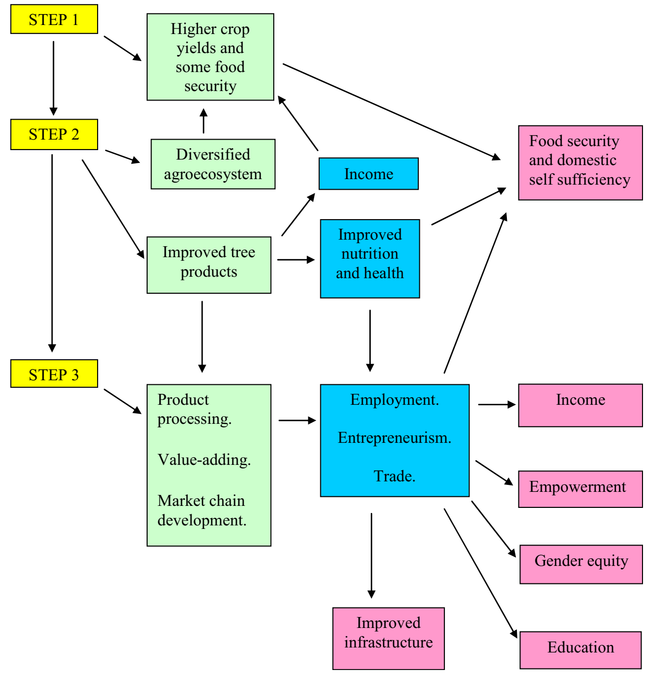


**Fig. 4** A conceptual framework for the proposed 3-step approach to Multifunctional Agriculture (Leakey 2012a): Step 1 = Rehabilitation of degraded land. Step 2 = Domestication of indigenous food and non-food species. Step 3 = Marketing and value-adding indigenous food and non-food products

local livelihood needs and expectations within the available local resource base (Degrande et al. 2014; Takoutsing et al. 2014), and through strategic partnerships (Franzel et al. 2004; Kiptot and Franzel 2015). They have been designed to help all members of a community, especially women and youths, to acquire information, knowledge, skills techniques and understanding appropriate to the adoption of agroforestry and tree domestication within the constraints set by the local environment (Tchoundjeu et al. 2002, 2006, 2010).

### 4.1 Sustainability

To minimise the need for external funding and to ensure commitment, the community is usually asked to provide the basic facilities in exchange for the RRCs services. To avoid ownership claims at a later date, these arrangements should be formalised. The farmers joining the RRC are expected to provide both land and labour for their own tree nursery. Creating a RRC involves considerable interaction with a community to gain their trust, explain its specific aims and objectives, and to affect a working relationship. This involves six steps (Table 5) aimed at engaging the community and identifying and encouraging the incentives to participate (Table 6). Establishment costs are variable as RRCs vary in their size, facilities and needs, but typically the main operational costs are limited to the costs of the manager and trainers provided by contributions from Development programmes, churches, NGOs and

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**Table 5** The six steps to creating a Rural Resource Centre (Degrande et al. 2015)

| Step | Activity |
|---|---|
| 1. | Conduct feasibility study: diagnose the information and training needs of farmers in the area. |
| 2. | Raise awareness amongst farmers and identify 'champions' for RRCs, i.e. organisations already involved in some farmer training and agricultural extension activities. |
| 3. | Train RRC staff on technical aspects but also on adult learning, communication, and extension skills. |
| 4. | Create tree nursery and gradually develop training and demonstration facilities. |
| 5. | Organise demonstrations, training, field visits, etc. for interested farmer groups; and update and refine extension knowledge to remain relevant. |
| 6. | Establish links and partnerships with other institutions to increase scope of intervention. |

charities. The activities of the Centre are also expected to generate income from the sale of plants and products, so that as the Centre grows into a diffusion hub that fosters many satellite tree nurseries in neighbouring villages, so maturing and becoming self-supporting and sustainable. Following this self-sufficiency strategy concurs with Principle 3 (Table 3), that the provision of skills and knowledge leads to greater sustainability than the provision of funds. This sustained activity after the termination of external funding has been the case in the Cameroon example. This self-help philosophy is important to ensure long-term success and recognition by national governments (Asaah et al. 2011; Degrande et al. 2012).

RRCs are also encouraged to interact with each other and to network with other villages outside the immediate community to create strong and diverse partnerships. The latter is specifically aimed at encouraging the dissemination of best practices through farmer-to-farmer interactions that encourage spin-off to neighbours forming satellite tree nurseries in their villages. RRCs have a local management committee from the community which can include the village chief, local mayor or other influential persons. Formal training provided by the staff, usually a NGO/CBO, covers subjects such as nursery practices, tree propagation (both from seeds and cuttings as well as grafting and marcotting), restoration of soil fertility, community dynamics, financial management, the use of microfinance, record-keeping, and product marketing. The biological, environmental, social and commercial components of the strategies, techniques, outcomes and impacts of this approach have been reviewed by Leakey (2014b).

Over the period 1998 to 2010 this programme of participatory domestication based on RRCs grew from 10 farmers in two villages to about 10,000 farmers in 500 villages over the North and Northwest provinces of Cameroon (Asaah et al. 2011; Degrande et al. 2012). Much of this was thanks to farmer-to-farmer dissemination of information, supported by local media publicity and community events (Tchoundjeu et al. 2006, 2010). As this programme grew, so the training activities of the RRCs and their relay organizations have evolved and expanded to provide new skills and knowledge, becoming highly successful and transforming the lives of the participating farmers and communities.

**Table 6** List of incentives mentioned by farmers in Cameroon that arise from their engagement in participatory domestication of indigenous food species

| Farm level | Perceived incentives of participation |
|---|---|
| 1. | Match with household desires |
| 2. | Match with tradition and culture |
| 3. | Improved well-being |
| 4. | Income generation |
| 5. | Improved and diversified diet |
| 6. | Self-help for self-reliance |
| 7. | Provides a vision of the future |
| External | |
| 1. | Opportunity for business and post-harvest processing |
| 2. | Improved market opportunities |
| 3. | Potential for Intellectual Property Rights |
| 4. | Sustainability |

## 5 Multifunctionality *versus* trade-offs

The International Assessment of Agricultural Knowledge, Science and Technology for Development emphasised the "inescapable interconnectedness of agriculture's different roles and functions" (IAASTD 2009) and the need to increase productivity by integrating interventions at many different levels (Kiers et al. 2008), with the aggregated effects typically exceeding the sum of their parts.

Food insecurity exists within the mix of outcomes arising from the complex set of interacting factors that come together to constrain productive farming in the tropics and sub-tropics; as described above in the Cycle of land degradation and social deprivation. Thus, to sustainably achieve food security, it is probably necessary to implement an equally interactive set of interventions aimed at stimulating multiple benefits and trying to reverse the whole cycle (Leakey 2017a). However, to what extent is multifunctionality a practical proposition?

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### 5.1 Multifunctionality

Multifunctionality is most clearly recognized in landscapes providing services such as genetic conservation, carbon capture, pollination, and other ecosystem or environmental services (Torquebiau et al. 2013; Estrada-Carmona et al. 2014) in mosaics with farmers' fields producing food and other products. In such systems, trees contribute biomass carbon which can be significant in global budgets (Zomer et al. 2016). However, care has to be taken when viewing landscapes as they are dynamic and can be progressing in different directions (Leakey and Prabhu 2017).

Landscape approaches are, however, widely seen to have benefits for the reconciliation of conservation and developmental trade-offs (Peng et al. 2011; Gu and Subramanian 2012; Sayer et al. 2013; Bailey and Buck 2016), although Phalan et al. (2011) have suggested that it will be necessary to prioritize some functions over others. Setting priority on nature conservation over agriculture, or *vice versa*, is however very contentious. So, it is encouraging when evidence is found that food production can be improved without harming the environment (Pretty et al. 2011). Good examples of these win:win systems can be seen in South East Asia where farmers cultivate rice in the valley bottoms and a wide mixture of other crops on the valley sides (Michon and de Foresta 1995). Interestingly, these mixed systems, which exceed three million hectares in Indonesia, progress through an agroecological succession that becomes a mature, productive and highly biodiverse multistrata agroforest (Leakey 2001a, 2001b, 2012a). Similar multi-cropping systems can also be seen in Latin America (Schroth and do Socorro Souza da Mota 2014), but are less common in Africa.

As we have seen earlier, this review is primarily about how to achieve multifunctionality at the farm level. Over the last century subsistence smallholder farmers in tropical environments, especially in Africa, have been encouraged to clear trees from their farms. This policy has failed to recognize that multi-cropping is especially advantageous to smallholder farmers who need to produce all their household food and non-food products on about two hectares without purchased inputs: with minimal risk of an ecological crash, and without the safety net of insurance or formal social services (Leakey 2012a). There is a need, therefore, to recognize the agroecological and other benefits arising from tree-based multi-cropping (Leakey 2014a). In this discussion, it is important to recognize that this does not mean that modern technologies such as improved crop varieties, artificial fertilizers, and pesticides should be rejected. Instead, it means gaining the best from different technologies while recognizing the constraints faced by subsistence farmers and finding ways to enable them to be overcome. This, as described in Step 3 above, can include finding ways to generate income so that they can gain access to modern technologies. None of this is incompatible with numerous other approaches to more sustainable agriculture (climate-smart agriculture, conservation agriculture, ecoagriculture, integrated landscape management, integrated rural development, organic agriculture or permaculture). However, it is unique in placing particular emphasis on the domestication of underutilized indigenous tree species producing traditionally important food and non-food products, as a means to enhance agroecology functions together with income generation (Leakey 2017c; see Conceptual Framework in Fig. 4). As we have seen, therefore, at the farm level, multifunctional agriculture is also about generating income and seeking alternative livelihood strategies for some of the current 80% of rural people engaged in subsistence farming.

### 5.2 Trade-offs

Turning now to the issue of trade-offs which are ubiquitous in life as we make choices between different options. Trade-offs typically describe the relationship between two or more variables in which an increase in one is associated with a decrease in others. They can have technical, institutional and international dimensions (FAO 1995) ranging from major policy-level impacts to the much less significant outcomes of day-to-day management decisions. The intensification of conventional agriculture has long been recognized to have substantial high-level trade-offs between productivity and sustainability in terms of food security, the exploitation of natural resources, wildlife conservation, environmental degradation and climate change (World Commission on Environment and Development 1987). Such trade-offs can be temporal or spatial in nature and very complex, as for example when seeking 'Payments for Ecological Services' (Villamor et al. 2017) in areas also associated with productive agriculture.

There has been a tendency to consider some of these high-level Trade-Offs as inevitable, and thus acceptable (FAO 1995). To some extent this reflects the ability in richer societies to offset the negative impacts of highly-productive, large-scale intensive agriculture by other policy/management decisions, such as the creation of conservation and watershed protection areas, use of waste management technologies and the support of social services, especially when addressing the important issues of global food shortages and famine *vis à vis* the environment. However, the situation in Developing Economies is very different, because subsistence smallholders have to be self-sufficient without financial access to agricultural inputs and are caught in food and nutritional insecurity. To feed their families and to survive, these subsistence farmers have little, if any, alternative but to follow current convention and to exploit their natural resources, regardless of the trade-offs.

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This raises the question "can a more appropriate approach to farming be developed that avoids or at least minimises, the damaging trade-offs arising from the consequences of the Cycle of land degradation and social deprivation?" Towards this end, van Wijk et al. (2016) have suggested that it is crucial to understand the dynamics that determine the nature of trade-offs, while the Earth Institute recognize three pillars for action: i) seek food security in environmentally, economically and socially sustainable ways, ii) minimise the negative impacts of agricultural intensification without compromising food security, and iii) improve livelihoods through improved food and nutritional security in low-income settings. The last of these was emphasised by Power (2010) who stated that agricultural management practices are key to obtaining beneficial ecosystem services to counter the dis-services of agriculture; while Klapwijk et al. (2016) have emphasised the importance of engaging all stakeholders in trying to resolve these issues. All these important points were discussed earlier in this review in the context of the 3-step approach to closing the yield gap.

#### 5.2.1 Production *versus* Environment

Probably the most commonly recognized high-level trade-off is that between farm productivity and the environment - both wildlife conservation and ecosystem services (Godfray and Garnett 2014). This is clearly seen in the permanent clearance of forests and woodlands associated with the transition from shifting cultivation to sedentary farming induced by growing population pressure. These issues were examined by the CGIAR's Alternatives to Slash-and-Burn Agriculture Programme (Palm et al. 2005) which concluded that "it is futile to attempt to conserve forests in developing countries without addressing the needs and objectives of local people". The approach presented in this review aims to do just that. The multiple biological, ecological, social, economic and environmental benefits described here suggest that it is possible to develop multi-cropping and multifunctional agriculture by creating agroecologically-based farming systems that also meet the essential financial needs of resource-poor households. There is, however, need for further understanding of nitrogen emissions resulting from biological nitrogen fixation (Rosenstock et al. 2015) *vis à vis* agroecological interactions in the soil. To some extent, this may be offset by the sequestration of carbon in the trees and enhanced soil organic matter (van Noordwijk et al. 2011). It is, however, clear that the agroecological component of this approach does have significant wildlife conservation benefits (Perfecto et al. 1996; Moguel and Toledo 1999; see also Table 7) by providing habitat for a wide range of local plants and animals threatened by habitat loss (Atta-Krah et al. 2004). The resulting improvement of agroecological function also reduces the incidence of pest attacks on crops (Leakey 2014a: Schroth et al. 2000). Thus, by creating an on-farm resource that is both productive and a good wildlife habitat it appears mature agroecosystems may also take deforestation pressures off protected areas, allowing natural forests and woodlands to recover from over-exploitation (Leakey and Prabhu 2017). It seems therefore that a wildlife- and farmer-friendly approach to agriculture does indeed mean that trade-offs can be seen as 'Trade-ons' due to highly beneficial synergies between ecosystem services and production (Nelson et al. 2009; Maes et al. 2012; Bailey and Buck 2016). Furthermore, by carbon storage in the trees and soil the environmental trade-off between farming and climate change can be minimised.

So, if wildlife and farmers can be winners in subsistence agriculture by addressing the ecological issues, is this also the case with the social and economic issues? We saw earlier that subsistence farmers trapped in hunger and poverty do not have the financial resources to purchase farm inputs.

#### 5.2.2 Intensive *versus* mixed cropping

Modern intensive agriculture, as conventionally practiced, is recognized as having negative environmental impacts, especially severe in Africa when negatively impacting production. To resolve this situation, interventions must both improve ecological sustainability and generate income, as proposed in Steps 2 and 3. It is suggested that by expanding and diversifying local markets for locally produced products the rural economy will become more vibrant. This approach may be a catalyst to lessen the spatial North:South trade-off arising from Globalization which constrains economic development in parallel with productive agriculture (FAO 1995). In the longer term, minimizing this Trade-off this might also benefit overseas economies as wealthier farmers in the tropics could purchase agricultural inputs from industrial countries; and new tropical industries could hopefully export products at a fair price without constraints from historical regulations. Currently, it is of interest to observe that there are also some examples of multi-national companies recognizing the advantages of promoting the smallholder cultivation of new tree crops in Africa, but so far this hasn't extended to value-adding in local communities (Leakey 2012a). As mentioned earlier, an important benefit from the income generation is that it allows numerous "spin-off" social benefits, such as greater equity for women and youths, access to greater access to education and health services. It also allows households to invest in local infrastructure and new enterprises (livestock, honey, fish farming, medicinal products, post-harvest processing and value-adding, etc.). All of these things enhance the empowerment attributable to weakening of the poverty Trade-off.

#### 5.2.3 Calories *versus* nutrients

Another major Trade-off associated with modern agriculture arises from the dominance of staple food crops in

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**Table 7** Examples of some assessments of the biodiversity in coffee and cocoa agroforestry systems in Mexico and their agroecology (See Leakey 2014a for other studies in Brazil, Cameroon, Costa Rica, Dominican Republic, Indonesia, India, Panama, Nicaragua)

| Organisms | Country | Crop | Reference |
|---|---|---|---|
| Biodiversity | | | |
| Monkeys | Mexico | Cocoa | Muñoz, Estrada, Naranjo, et al. 2006 |
| Birds | Mexico | Cocoa | Greenberg 2000 |
| Soil coleoptera | Mexico | Coffee | Nestel, Dickschen & Altieri, 1993 |
| Mammals | Mexico | Coffee | Gallina, Mandujano & Gonzalez-Romero, 1996 |
| Ants | Mexico | Coffee | Perfecto and Snelling 1995 |
| Arthropod | Mexico | Coffee | Perfecto, Vandermeer, Hanson, et al. 1997 |
| Birds | Mexico | Coffee | Perfecto, Vandermeer, Bautista, et al. 2004 |
| Birds | Mexico | Coffee | Greenberg, Bichier & Sterling, 1997 |
| Agroecological interactions | | | |
| Birds, ants, and leaf miners | Mexico | Coffee | de la Mora, Livingston, & Philpott, 2008 |
| Ants and phorid flies | Mexico | Coffee | Pardee and Philpott 2011 |
| Birds | Mexico | Coffee | Philpott and Bichier 2012 |
| Birds and caterpillars | Mexico | Coffee | Perfecto, Vandermeer, Bautista, et al. 2004 |

agriculture and their relative deficiency in micro- and minor nutrients when compared with nutrient-rich traditional foods from forests and woodlands (Leakey 1999). This has led to heightened incidence of malnutrition in rural communities (Welch et al. 1997).

A number of studies have found positive socio-cultural and nutritional impacts from participatory domestication of highly nutritious indigenous fruits and nuts (Wynberg et al. 2002; Shackleton et al. 2009; Asaah et al. 2011) indicating the benefits of combining nutritionally rich species with those for calorie production. Thus, the cultivation of new tree crops as components of the farming system can, as explained earlier (section 3), enhance the productivity of staple foods by closing the Yield Gap, and relieve malnutrition by diversifying the diet. This is also entirely compatible with the diversification of common staple food crops with highly nutritious and culturally important small grain crops such as pearl millet, finger millet, or sorghum, and legumes.

### 5.3 Outcomes

Pulling together the information provided above has led to the concept that the cultivation of socially modified organisms (SMOs) and the commercialization of their products in local and regional markets is illustrating a new, sustainable and much more productive paradigm for agriculture in Developing countries (Leakey 2017b). This review has suggested that this novel approach to addressing the food security and related socio-economic issues in tropical/subtropical agriculture has potential to overcome some of the key constraints limiting greater food production in harmony with the environment. In particular, this is illustrated by the case study from Cameroon which has reported positive results and outputs at the community level (Table 8), and extrapolation based on research literature suggests that there are reasons to be optimistic about subsequent outcomes and impacts if this approach is up-scaled and out-scaled (Table 8), with other potential outcomes at the regional and global level (Leakey and Prabhu 2017).

### 5.4 The future

The challenge now is to harness multiple benefits from the cultivation of SMOs in tree-based multi-cropping systems. This will require: i) greater institutional capacity, the use of participatory and gender-analysis approaches together with wider concepts and methodologies for impact assessment and institutional learning (Lilja and Dixon 2008); ii) the complementary multidisciplinary perspectives and solutions called for by Poppy et al. (2014), and iii) better communication towards advances in policies that link biodiversity and ecosystem services with human well-being (Bennett et al. 2015). Making deliberate efforts to capture 'Trade-ons' in this way should lead to greater progress towards the new 2030 Sustainable Development Goals (Leakey 2017d).

## 6 Triggering change towards impact - the wider context

### 6.1 International

The context of efforts to resolve the interconnected issues of environmental degradation, hunger, malnutrition

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**Table 8** The local level cascade of expected outputs and outcomes from implementing agroforestry to deliver Multifunctional Agriculture. Thirty two of these outputs have been reported (Tchoundjeu et al. 2010; Asaah et al. 2011; Degrande et al. 2014; Leakey 2014c)

| INTERVENTION | Results | Outputs | Expected Outcomes | Expected Impact |
|---|---|---|---|---|
| **Step 1 – Harness Biological Nitrogen Fixation by planting leguminous trees** | • Replenishment of soil nitrogen | Crop yield increased | Partial closure of Yield Gap | Enhanced food security |
| | • Enhanced agro-biodiversity in soils | Improved agroecological function below ground | Improved soil health – reduced risk of crop failure | Enhanced food security |
| | | • Increased organic matter | Carbon sequestration | Some mitigation of climate change |
| | | • Reduced erosion | Reduced soil run-off | Enhanced soil protection |
| | | • Enhanced water infiltration | Groundwater recharge | Water-table replenished |
| | • Production of tree fodder | Increased livestock production | Increased consumption of meat, dairy products, etc. | Better dietary health and income generation |
| | • Production of bee fodder | Enhanced pollination | Bee keeping for honey production | Income generation and improved dietary health |
| | • Production of fuel wood | Reduced labour on fuel collection | Improved energy self-sufficiency and income | Enhanced well-being |
| | • Business opportunity | Establish tree nurseries | Sale of tree seedlings | Income generation |
| **Step 2 – Domestication of indigenous food / medicinal trees** | • Tree planting and replenishment of depleted and threatened resource | Enhanced agro-biodiversity in soils | Improved agroecological function below ground and greater soil health | Reduced risk of crop failure and enhanced food security |
| | • Production of useful tree products | Domestic consumption | Improved diet and nutrition | Better household health |
| | | • Marketing opportunity | Local trade | Income generation |
| | | | • Post-harvest processing for wider trade year-round | Income generation |
| | • Establish participatory domestication process | Community engagement in Rural Resource Centres | Acquire skills and understanding | Community empowerment and self-sufficiency |
| | | • Self-help process | Better self-image | Improved self-esteem |
| | | | • Satisfaction | Enhanced well-being |
| | | • Involvement of women and youth | Gender and youth equity | Healthy rural communities |
| | • Selection of elite trees | Production of superior planting stock | Farm diversification | Improved agroecological function below ground |
| | | • Multiplication of superior varieties | Greater uniformity of product quality | Reach more regulated markets |
| | | | • Opportunity to match products to industrial market needs using 'ideotypes' | Reach more specialist or niche markets (even export markets) |
| | | | • Opportunity to market further up the value chain | Regional trade and income generation |
| | | • Farm intensification | Greater total productivity | Enhanced social and economic lifestyle |
| | | | | • Opportunities to purchase farm inputs and develop farm infrastructure |
| **Step 3 - Commercialization of tree products** | • Post-harvest processing and packaging | Longer shelf life | Opportunity to market outside production 'season' | Increased income generation |
| | | | • Opportunity to expand trade geographically | Increased income generation |
| | | • Creation of local business enterprises | New entrepreneurism and job opportunities | Increased income generation |
| | | | • Create opportunity for local equipment fabricators | Local employment and income generation |
| | | | • Opportunity for microfinance | Greater income generation |
| | | | • Opportunity for women and youth | Greater social equity |
| | | | • Enterprise diversification | Diversified and healthy rural economy |
| | | | • Enhanced wealth | Opportunities to purchase education and health care |
| | | | | • Opportunities to develop local infrastructure |

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and poverty can be traced back to the "Club of Rome" (Meadows et al. 1972) and subsequently to a series of UN Conventions and international reports (Millennium Ecosystem Assessment 2005; Comprehensive Assessment of Water Management in Agriculture 2007; Global Environmental Outlook 2007; International Assessment of Agricultural Science and Technology for Development 2009), and the declaration of the UN Millennium and the 2030 Sustainable Development Goals. Over this period public attitudes toward environmental issues have changed considerably, but real progress on the ground has been more limited. It seems, therefore, that either some 'hidden agenda' is inhibiting the political will to invest in progress, or some essential element is missing. One possible explanation is that most of the calls for action have focussed on the desired outcomes, rather than the processes needed to achieve these outcomes. In this connection, it is interesting that some very recent initiatives are more action oriented. For example, under the Bonn Challenge the African Union has mandated to set up the Africa Forest Land Restoration Initiative (AFR100) to restore 100 million hectares of degraded land by 2030 and thereby to capture associated benefits for food security, climate change resilience, and poverty alleviation. This plan is matched by national government mandates to contribute 10% of national budgets to the initiative.

### 6.2 Africa

This unique political move by African nations places much greater emphasis on the implementation process. Thus, the congruence between this African initiative and the strategies, techniques and experience outlined in this review seems to offer hope for the future. Interestingly, two other international R&D initiatives are also highly relevant. The first is a new CGIAR research flagship programme "Forests, Trees and Agroforestry: Livelihoods, Landscapes and Governance" with two relevant components "Tree genetic resources to fill production gaps and promote resilience" and "Enhancing how trees and forests contribute to smallholder livelihoods". The second in the emergence of a Development-oriented Agroforestry Alliance for Africa is made up of a number of NGOs already engaged in rural development programmes in Africa. It aims to be the catalyst to accelerate the upscaling of agroforestry to reach many million more farm families and its mission is to "restore and mainstream productive tree-based land use systems for the benefit of peoples' livelihoods and health, restore productivity to degraded agricultural land and to conserve forests, and to address climate change across Africa". It is very encouraging that together these recent developments seem to herald an African solution to the problems of African agriculture (Leakey 2014e). Perhaps this is the realization of an African proverb quoted in anticipation by Leakey and Izac (1996):

> "*If many little people, in many little places, do many little things, they can change the face of the earth*"

## 7 Conclusions

Trees are keystones in agroecosystems providing a three-dimensional structure to the productive vegetation that creates numerous ecological niches above- and below-ground for the organisms that deliver resilience and sustainability. Crucially, they also provide a wide array of useful, nutritious and marketable products for domestic use and new businesses and industries. It is suggested that this enunciation of the combination of restored agroecological function with income generation provides 'Trade-ons' offering a way out of hunger, poverty and environmental degradation, by reversing the cycle of land degradation and social deprivation, closing the yield gap and minimising the common trade-offs, and so meeting the needs of poor, smallholder farmers.

As local income-generating activities grow, the capacity of these rural households to purchase foods and goods produced elsewhere should also expand, so stimulating the local economy. Thus, by delivering opportunities for self-determination, more judicious and equitable use of natural capital, and a wider range of livelihood options, the achievement of multifunctional agriculture could: i) improve food and nutritional security, ii) create new and more sustainable horizons for local economic and social well-being, and iii) stimulate global economic growth by expanding the economy of those countries with daily income per capita below the median (Fig. 1).

Finally, perhaps, this can be summed colloquially by saying the socially modified crops cultivated in tree-based mixed cropping systems can be hunger-busting, farmer-friendly, wildlife-friendly, climate friendly, wealth-promoting and health-giving. No doubt, some will say this is a pipe dream, but should we not be seeking a world that is much healthier, environmentally, socially and economically - one able to feed all its population without severe poverty. I believe we have the knowledge, understanding and capacity to do this; but do we have the will and the vision?

## Compliance with ethical standards

**Conflict of interest** The author declares that he has no conflict of interest.

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**Roger Leakey** DSc, PhD, BSc, NDA was a former Director of Research at the International Centre for Research in Agroforestry (ICRAF 1993–1997) and Professor of Agroecology and Sustainable Development of James Cook University, in Cairns, Australia (2001–2006). He has been Vice President of the International Society of Tropical Foresters and is Vice Chairman of the International Tree Foundation. He holds a number of Fellowships in learned societies, universities and international research centres. He was a Coordinating Lead Author in the International Assessment of Agricultural Science and Technology for Development (IAASTD) which was approved by 58 governments in an Intergovernmental Plenary meeting in Johannesburg, South Africa in April 2008. This Assessment examined the impact of agricultural knowledge, science and technology on environmentally, socially and economically sustainable development worldwide over the last 50 years and suggested that to meet these challenges agriculture has to advance from a unifunctional focus on food production and to additionally embrace more environmental, social and economic goals – i.e. to become multifunctional. To advance agriculture in this direction, the author initiated what has become a global agroforestry programme to start the domestication of wild fruit and nut trees that were the staple diet of people before the Green Revolution. This initiative was proposed by farmers in Cameroon when they were asked what they would like to see done to improve their livelihoods and farming systems. This approach was implemented by ICRAF (now the World Agroforestry Centre) in the 1990s and has been very successful, with many impacts exceeding the Millennium Development Goals. This involved the domestication of new food crops that are unknown to most of us and their integration with staple foods on-farm to enhance environmental, social and economic sustainability by closing the Yield Gap, commonly the cause of food insecurity. The value-adding and processing of these highly nutritious tree products is also creating local business opportunities and creating employment, adding to the positive benefits of this approach to farming. In his book "*Living with the Trees of Life – Towards the Transformation of Tropical Agriculture*" (CABI, 2012) Roger presents the story of these changes in agricultural philosophy within the context of the authors personal experience of travelling and working in many countries of north, central and south America and the Caribbean; Africa; the Middle East; and south, south-east Asia and Oceania. The academic publications underpinning this book have been published in a recent book "*Multifunctional Agriculture – Achieving Sustainable Development in Africa*".