Chapter 39

Toward Multifunctional Agriculture – An African Initiative

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SUMMARY

Sustainable Intensification is especially important in Africa where the need is greatest. We present eleven targets for action, paying specific attention to the needs of poor smallholder farmers in Africa. We describe multi-cropping systems integrating new crops developed from culturally-important traditional food species that intensify and enhance the productivity of smallholder farms by reducing the yield gap and providing multiple environmental, social and economic benefits. These include energy security and the creation of new local business and employment opportunities off-farm. We describe the integration of relatively simple activities to promote better soil fertility and income generation at the community level through the diversification of farming systems with trees, other food crops and livestock that increase total production. This approach, which is best developed in Cameroon, has been shown to meet the needs of food and nutritionally insecure smallholder farmers who also suffer poverty and social injustice at multiple, nested scales from farm through to landscapes and regions. This form of intensification integrates numerous different concepts of enhanced agricultural sustainability with conventional modern agricultural technologies and reverses the Cycle of Land Degradation and Social Deprivation. This leads to integrated rural development and visions of a better world. Consequently, we recommend that those wishing to address the complex and interacting issues which are the targets of the 2030 Sustainable Development Agenda should rethink the interventions needed by African farmers.

INTRODUCTION

Agronomy in the developing world has become a polemic issue in which agreement focuses around wide recognition that "business as usual" is not an option for the future (e.g., MEA, 2005; IAASTD, 2009). After many years of discussion about the sustainability of agriculture, especially in the tropics and subtropics, the concept of sustainable intensification is gaining traction as a result of being increasingly well elucidated and justified (Royal Society, 2009; Garnett et al., 2013; Pretty and Bharucha, 2014). Additionally, awareness is increasing that progress in this direction will depend on the integration of biological, environmental, and social sciences to deliver benefits of practical value for food security, poverty alleviation, and mitigation of climate change, etc. Toward this objective Garnett et al. (2013) have provided underpinning premises and areas of interfacing policy (Table 39.1), while Pretty and Bharucha (2014) have identified requirements for policy change. Within this wider debate there are also calls for strategies aimed at resilience (Bennett et al., 2014) and other holistic concepts to ensure that food security is achieved with environmental and social benefits conferring land-use efficiency (Loos et al., 2014), and the creation of "green economies" respecting imperatives such as Rockström's Planetary Boundaries (Rockström, 2009). While we agree with much of the general thrust of these analyses, we believe the debate so far is not putting sufficient emphasis on the risk and path dependency of the options seminal to sustainable intensification of smallholder agriculture in Africa. Pretty et al. (2011) have, however, surveyed 40 existing projects in 20 African countries and found examples that demonstrate that food outputs can be improved without harm to the environment. Typically these also fostered social, economic, and cultural relations, and enhanced rural and urban livelihoods. While the study identified some common constraints affecting African agriculture, and listed seven key requirements for

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TABLE 39.1 Premises and interfacing policies for multifunctional landscapes (Garnett et al., 2013).

Premises for sustainable intensification

1. Conventional modern agriculture has a supply side problem based on underproduction to meet growing demand for food.
2. Increased production should be achieved without the use of an increased area of land, because of the environmental cost of clearing more land for agriculture.
3. Food security requires attention to environmental sustainability.
4. SI merits diverse approaches (conventional, high-tech, agroecological, and organic) in different biological and social contexts.

Policies interfacing with sustainable intensification.

1. Biodiversity and land use
2. Animal welfare
3. Human nutrition
4. Rural economics
5. Sustainable development

TABLE 39.2 Key requirements for policies to support the scaling up of sustainable intensification to larger numbers of farms (Pretty et al. 2011; Pretty and Bharucha, 2014).

1. Scientific and farmer input into technologies and practices that combine crops and animals with appropriate agroecological and agronomic management.
2. Creation of novel social infrastructure that both results in flows of information and builds trust among individuals and agencies.
3. Improvement of farmer knowledge and capacity through the use of farmer field schools, videos and modern information communication technologies.
4. Engagement with the private sector to supply goods and services (e.g., veterinary services, manufacturers of implements, seed multipliers, milk, and tea collectors) and development of farmers' capacity to add value through their own business development.
5. A focus particularly on women's educational, microfinance and agricultural technology needs, and building of their unique forms of social capital.
6. Ensuring that microfinance and rural banking is available to farmers' groups.
7. Ensuring public sector support to lever up the necessary public goods in the form of innovative and capable research systems, dense social infrastructure, appropriate economic incentives (subsidies, price signals), legal status for land ownership, and improved access to markets through transport infrastructure.

policy interventions (Table 39.2), it did not seek innovative practical interventions aimed at new approaches to maximizing productivity, farmer well-being, and environmental rehabilitation.

The problems of African agriculture are a special case. There are intricately enmeshed issues of land degradation and poverty (Vosti and Reardon, 1997; Scherr, 2000); thus, interventions to achieve sustainable intensification must combine good land husbandry and functioning agroecosystems, with steps to improve the income, livelihoods and well-being of extremely poor farmers (Leakey, 2012b). Critically, it is important to help these farmers to gain entry into the cash economy and be able to adopt more productive land-use practices as well as acquire the ability to purchase food and other day-to-day goods and services (Leakey, 2010, 2012a). In other words, sustainable intensification is also about improving the lives of people so that more intensive and productive farming is associated with both better land-use management, empowered farmers with better livelihoods, and enhanced economic development. In this way, some members of the rural population will be able to get out of the subsistence agriculture that is driving land degradation, and into either new local business development or local employment. To broaden the debate we therefore present some action-oriented targets for sustainable intensification offering a more developing country/low-input, smallholder agriculture view, involving agroforestry. This is based on experience in the tropics, and particularly Cameroon, and has an income generation and agroecological/landscape perspective in which the importance of diversity (social, economic, ecological and environmental) is stronger (Leakey, 2012b,e). We believe that this wider perspective is needed to illustrate interventions that can "tick the boxes" of some expected outputs and then formulate policies more relevant to smallholder agriculture in the tropics and to enhance investment in support of sustainable intensification.

To start by stating the obvious, the purpose of agriculture is to meet realistic food and nutrition needs of all people cost-effectively, equitably and with resource efficiency. To this goal, the International Assessment of Agricultural Science and Technology for Development (IAASTD, 2009) added multifunctionality embracing livelihood and sustainability goals. Despite the obvious successes over the last 60−70 years in crop and livestock breeding, there is clear evidence from an analysis of 297 impacts of Agricultural Knowledge, Science and Technology that we are not currently living up to these wider expectations (Leakey et al., 2009). This is further emphasized by the enunciation of the new

2030 Sustainable Development Goals which embrace the need for agricultural impacts across a wide range of interrelated social, economic and environmental outcomes, and by calls for better communication to promote advances in policy that link biodiversity and ecosystem services with human well-being (Bennett et al., 2015).

WHAT ARE THE ISSUES?

In the early days of agriculture, yields were sustained by implementing periods of fallow that harness natural processes of soil fertility replenishment and the maintenance of agroecosystem function. Then, with increasing intensification, monocultures were developed involving improved crop varieties and artificial inputs such as chemical fertilizers and pesticides, irrigation, and mechanization (Pingali, 2012); but its implementation has come with an environmental cost. This industrial approach to agriculture is most effective in industrial countries where only a small proportion of the population is engaged in farming and the farmers can use capital-intensive technologies on large farms with fertile soils. In this situation, the high financial costs of industrial agriculture are absorbed by economies of scale. While maintaining high crop yields artificially is biologically possible in the tropics and subtropics—as is seen on research stations (Sileshi et al. 2008a, 2014)—economies of scale are not available to poor smallholder farmers in the tropics and subtropics. These farmers typically have about 2 hectares (1–5 ha) of land (sometimes in small, isolated, and scattered parcels), and do not have access to cash income to purchase modern technologies (African Development Bank, 2015). In addition, in Africa, modern conventional agriculture commonly comes with high resource use, inefficiency and often with considerable social and environmental "externalities" (Pretty, 2008). Life in rural areas is also hampered by poor roads and local transport, lack of local infrastructure, issues of land tenure and ownership, poor market information, and poor extension services for technical support. For these farmers, desperately trying to support their dependent households by self-sufficiency, without the safety net of insurance and social services, mixed-cropping is a strategy for risk aversion. However, with declining staple crop yields, the area committed to them has to increase. Together, these problems combine and seem to make Africa the least responsive to the Green Revolution (Evenson and Gollin, 2003) and in need of special consideration (Nin-Pratt and McBride, 2014).

The reality is that in nearly half the world, food production by extremely poor farmers is severely constrained by poverty and the impacts of deforestation, overgrazing, and nutrient mining, which lead to land degradation and soil infertility (Leakey, 2013), outcomes which can be exacerbated by tillage, especially mechanical tillage. Together these impacts create a complex downward spiral in crop productivity that involves the loss of soil fertility and above- and belowground biodiversity. Together these cause a breakdown of the agroecological functions that are an important part of ecological sustainability. Together, the consequence of these negative impacts is lower crop yields and subsequently a decline in livelihoods, which then traps farmers in poverty, hunger, and malnutrition—the cycle of land degradation and social deprivation (Fig. 39.1) (Leakey, 2010, 2012b,e). A critical consequence of this is that farmers in Africa are not able to implement the Green Revolution technology package, and hence farm yields are well below the biological potential (Leakey, 2012a). For example, average maize yields in Africa are about 1.5 tonnes per hectare, while the biological potential of the varieties being used is around 7 tonnes per hectare (Sebastian, 2014). This very substantial yield gap is the result of the inaccessibility of technology due to low income, and hence is an efficiency gap (van Noordwijk and Brussaard, 2014) that could be filled by appropriate technology that addresses the supply side issues (Garnett et al., 2013). Closing this yield gap across Africa would substantially enhance food security in the continent as well as having substantial environmental, economic, and social benefits (Leakey, 2012b,e). Furthermore, in addition to addressing food insecurity in a world with a rapidly expanding population, sustainable intensification has to address the other Sustainable Development Goals. This will require complementary multidisciplinary perspectives and solutions to resolve issues of food availability, the stability of supply, income generation, social injustice, access to markets, and the nutritional utility and safety of food (Poppy et al., 2014). These are the result of complex and challenging issues, now being exacerbated by climate change, which together exemplify the need to examine the inextricable links between ecosystem services and human well-being in novel and inter- and transdisciplinary ways (Leakey, 2013, 2014f; Poppy et al., 2014). To guide this process we identify 11 critical targets for transformative action (Table 39.3). Some of these targets interact, and so have overlapping impacts, but are presented separately here for emphasis of their importance, and because of the failure of many agencies to engage in integrated approaches to development.

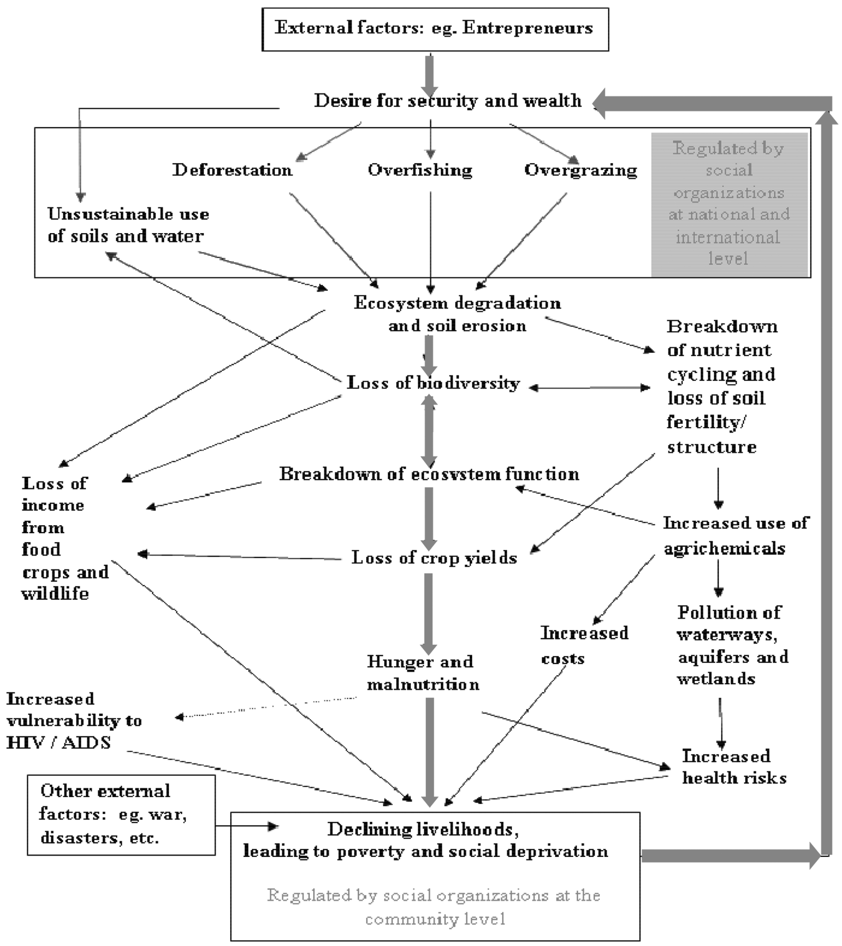

FIGURE 39.1 The cycle of land degradation and social deprivation. *Modified from Leakey et al., 2005a.*

TABLE 39.3 Eleven targets for action to transform the productivity and sustainability of tropical agriculture and associated rural development.

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: (1) better nutrition and (2) 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.
11.	Maintain global functions.

Target 1: Recognize Need for Different Approaches—Both Agronomic and Economic

Many advocates of change in agriculture have called for more sustainable systems (e.g., MEA, 2005; IAASTD, 2009). The suggestions often show remarkable polarity, at one extreme by greater use of molecular science to create genetically modified crops with resistance to herbicides and biotic/physical stresses, and at the other end certified organic agriculture free of pesticide use and genetically modified organisms. We consider that a more appropriate target embraces elements of both approaches.

Julian Cribb (2011) in his book, *The Coming Famine*, also recognizes the need to embrace the philosophical divide as these different approaches are appropriate in different places and circumstances. The requirement for diverse approaches in different biological and social contexts for the achievement of sustainable intensification is also recognized by Garnett et al. (2013). We concur with these assessments and particularly want to emphasize that what is appropriate in industrial nations of temperate latitudes almost inevitably is not relevant to developing nations in the tropics and subtropics. For example, we have to recognize that many tropical farmers moving from shifting cultivation to sedentary smallholder systems have been unable to sustainably implement the latest wave of agricultural intensification—the Green Revolution—due to their lack of income for the purchase of the inputs. It is therefore premature to try to implement the biotechnology revolution while they face severe land degradation and socioeconomic constraints that prevent the achievement of the already improved biological potential of modern crop varieties.

Typically, under conventional approaches to agriculture in the tropics, farmers can generate income by growing commodity products such as tea, coffee, cocoa, cotton, tobacco, and rubber. However, there are two problems here. Firstly, the prices paid to tropical farmers for these commodity crops are regulated in industrial countries, raising issues of "fair trade"—for example, smallholder tea, coffee, and cocoa farmers receive only 3−10% of the retail price (Curtis et al., 2013). Secondly, the average household of 6−8 people only has about 2 ha of land to provide all their needs. When the food crops have very low yields, there is little possibility of available land to grow cash crops for income generation. Another factor in the poverty debate arises from the fact that many youths migrate to urban areas to seek employment. This leaves the old on the farms and a labor shortage. Interestingly, in a number of countries, this is leading to a switch to tree crops that have a lower labor demand (Place, 1995; Place and Otsuka, 2000).

Recognizing all these problems, we believe a stepped approach is needed to resolve the issues constraining the productivity of tropical agriculture. Thus, before further crop breeding to enhance yield potential, there is a need to promote good crop husbandry and land rehabilitation. This can then be followed by a focus on income generation so that hundreds of millions of poor tropical farmers can enter the cash economy and purchase the agricultural inputs needed to intensify their production and completely close the yield gap that is common in the cultivation of staple food crops (Leakey, 2012b,e, 2013). As increasing crop yields will only address one aspect of what makes individuals, households, communities and nations food secure or insecure, we present in what follows an integrated approach to additionally resolving the current issues of land degradation, nutritional insecurity, poverty, social reform, and economic growth—steps toward the sustainable intensification of tropical agriculture, especially in Africa. This involves experience from work not generally recognized as mainstream agriculture, e.g., in agroecology (Altieri, 2002; Gliessman, 1998; Leakey, 2014e) and agroforestry (Leakey, 2012b; Leakey and Asaah, 2013).

Target 2: Restore and Maintain Soil Fertility for Sustained High-level Production

The fertility of the agricultural soils of sub-Saharan Africa have been depleted by years of weathering and nutrient leaching, resulting in highly acidic soils (<5.5 pH) which are vulnerable to aluminum toxicity (Sebastian, 2014) and reduced phosphorus availability and uptake (Rowell, 2014). Soil acidity affects about 32% of cropland. In total about 80% sub-Saharan Africa's cropland is considered highly unsuitable for agriculture, because farmers' yields are limited (Sebastian, 2014). A recent report estimates that nearly 180 million people in sub-Saharan Africa are negatively impacted by this land degradation (Naylor, 2014) and suggests that the economic cost in terms of lost yield is about $68 billion (Naylor, 2014). This depletion of nutrient resources is exacerbated by the frequent or continuous cropping of extremely poor farmers who are desperate to feed their families, but lack the income to purchase fertilizers. This soil degradation also results in agroecological problems due to loss of soil biodiversity, reduced nutrient and carbon recycling, loss of soil structure, poor water infiltration, soil erosion, and consequently problems of water uptake (Sileshi et al., 2014). Early approaches to agroforestry's "Diagnosis and Design" (Raintree, 1987) recognized that a different and more appropriate approach was needed, as financially intensive options of maintaining soil fertility are not available to poor smallholder farmers in the tropics and subtropics.

Unfortunately, inorganic fertilizers are less efficient at ameliorating the physical and biological degradation of soils; thus, organic methods of restoring fertility are especially beneficial on degraded land. However, the use of manure and organic mulching is constrained in large-scale farming systems by the difficulty of producing sufficient organic matter (10–40 Mg ha^{-1} $year^{-1}$) to balance the quantity of nutrients lost (Mafongoya et al., 2006). An alternative option is to use leguminous plants that fix atmospheric nitrogen through a symbiotic association with soil bacteria on their roots (Sprent, 2009). Nitrogen is the soil nutrient most commonly limiting plant growth and can be very effectively replenished by this inexpensive and relatively simple biological process. Unfortunately, the biological replenishment of other major soil nutrients like phosphorus and potassium is only possible by recycling biomass.

Some nitrogen-fixing leguminous plants are food crops like beans; some are fodder species which produce 23–176 kg N ha^{-1} $year^{-1}$ (Herridge et al., 2008), while others are shrubs and small trees which when grown at high density can produce 300–650 kg N ha^{-1} $year^{-1}$ (Nygren et al., 2012). Many years of research in Africa (Cooper et al., 1996; Buresh and Cooper 1999; Sanchez, 2002) have demonstrated that 2–3 year improved fallows with leguminous shrubs and trees will enhance soil nitrogen such that typical yields from cereal crops grown on formerly degraded soils are increased two- to threefold (Sileshi et al., 2008a) in ways that are easily attainable by poor smallholder farmers (Kwesiga et al., 1999). Likewise, in the drylands, stands of *Faidherbia albida* trees play a similar role in the so-called evergreen agriculture (Garrity et al., 2010). These yield responses, which are also reported for vegetables (cabbage, onion, rape, paprika) (Sileshi et al., 2014) and groundnuts (Degrande et al., 2007), in response to biological nitrogen fixation have led to these trees and shrubs being called "fertilizer trees." However, as with the use of inorganic fertilizers, N_2O emissions are associated with increased levels of biologically fixed soil nitrogen (Dick et al., 2006; Hall et al., 2006).

Sileshi et al. (2014) emphasize that both the organic/biological benefits of fertilizer trees and the inorganic replenishment of soil nutrients by artificial fertilizers are important for food production and that decision makers in development agencies should take advantage of the synergy between biological and mineral fertilizers rather than focusing on the "organic vs. inorganic" debate. We support this conclusion in Target 5. However, as will be seen in the following, there are other benefits of fertilizer trees, especially for the rehabilitation of degraded land. Nevertheless, one advantage of organic inputs is that, in contrast to inorganic nitrogen, much of the unused nitrogen from organic inputs is typically incorporated into soil organic matter or taken up by the trees for future recycling.

Soil health is also enhanced by the biological nitrogen fixation of leguminous trees and shrubs as it increases aggregate stability, porosity, and hydraulic conductivity by increasing the soil organic matter and improving both soil structure and water infiltration (Table 39.4). These changes have also been shown to improve water use efficiency and rain-use efficiency (Sileshi et al., 2011). The synergy between soil health and soil fertility is important for the attainment of good crop yields, and for resilience and sustainability.

TABLE 39.4 Some examples from Msekera, Zambia of changes in soil physical properties (0–20 cm) due to fertilizer trees/shrubs (Fert Tree) in improved fallow and the control (sole maize) and the % change.

Variable	Tree species	+ Fert Tree	Control	% Change
Bulk density (Mg m^{-3})	Gliricidia	1.39	1.53	−9.2
	Gliricidia	1.40	1.42	−1.4
Aggregate stability (mm)	Sesbania	8.3	61.2	36.1
Infiltration rate (mm h^{-1})	Gliricidia	16.0	4.0	300.0
Time to run-off (min)	Sesbania	7.0	3.0	133.3
Drainage (mm)	Sesbania	56.4	15.8	257.0
	Sesbania	10.9	1.0	990.0
	Sesbania	61.1	7.6	703.9
	Sesbania	10.7	5.7	87.7
Penetrometer resistance (Mpa)	Sesbania	2.2	3.2	−31.3
	Pigeon pea	2.9	3.2	−9.4

After Sileshi, G.W., Mafongoya, P. Akinnifesi, F.K., Phiri, E., Chirwa, P., Beedy, T., et al., 2014. Agroforestry: Fertilizer trees. In: Encyclopedia of Agriculture and Food Systems, Vol. 1, Neal Van Alfen, editor-in-chief. Elsevier, San Diego, pp. 222–234.

An additional benefit of enhanced yield in cereal crops is increased stover production (up to 2 tonnes ha^{-1}), which can be used as livestock fodder.

These leguminous trees and shrubs can simultaneously be grown for their environmental services, e.g., along contours to reduce soil erosion (Angima et al., 2001); to control serious weeds (Sileshi et al., 2008c, 2014); or they can also double-up as productive crops producing building poles, fuel wood, or livestock fodder, and in some cases edible fruits and seeds. Furthermore, they can treble-up as bee fodder for better crop pollination and honey production (Degrande et al., 2007). On the negative side, fast-growing trees grown in association with food crops can compete in complex ways for light, water, and nutrients, especially early in an agroecological succession (Ong and Leakey, 1999), while in the longer term having numerous agroecological benefits (see Target 3). Nevertheless, depending on complex spatial and temporal interactions between the biological, physical, hydrological, and climatic components of the system, there is potential to derive considerable benefits by optimizing the use of different tree and crop species, appropriate to the type, depth and fertility of the soil, the quantity and distribution of rainfall, and the capture of solar radiation (Ong et al., 2014).

It is also relevant to recall here that overdependency on inorganic artificial fertilizers is one of the environmental "costs" of high-input agriculture which impinges on the sustainability debate due to the high fossil-fuel usage during their manufacture, and the contamination of aquifers and pollution of rivers and the ocean, which results when they enter the groundwater (Molden, 2007).

Target 3: Restore and Maintain Agroecological Processes for Sustained and Resilient Production

In the past 10–15 years, increasing efforts have been made to maintain or increase flows of ecosystem services, while also increasing both yields and farm profitability. These have been promoted under a variety of names and approaches. A review of over 280 such interventions over 37 million hectares found evidence of improved crop yields together with enhanced water use efficiency and other ecosystem services, including carbon sequestration (Pretty et al., 2006).

While fertilizers and pesticides provide a technological "fix" substituting for the natural processes in high-input farming systems, they typically have negative impacts on agroecological processes and so contribute to the loss of soil health. In this situation, harnessing natural processes of fully functional agroecosystems is a more appropriate and effective alternative (Altieri, 2002; Gliessman, 1998), recognized in African traditional knowledge (Boafo et al., 2015). Like natural vegetation, agroecosystems progress through a succession of stages from pioneer to more complex and mature assemblages (Leakey, 1999b). This is the natural process of recovery from severe ecosystem damage, such as land clearance. In farming systems, a crop monoculture is an extreme pioneer stage which can be maintained ad infinitum under perfect situations, or encouraged to mature by diversification of the farming system either at the field level in a landscape mosaic, with diversification with other crops (especially perennials) creating niches above- and belowground for wild organisms to occupy as it matures (Leakey, 2014e). On and below the soil surface, these organisms decompose the biomass, and return the nutrients back to the plants for their continued growth (Barrios et al., 2012). These processes are the driving forces of the nutrient and carbon cycles—the foundations of soil fertility and the reduction of CO_2 emissions to the atmosphere (Leakey 1999b). The greatest opportunity for practices in which trees and crops are grown simultaneously is therefore to fill niches within the landscape where soil and water resources are currently underutilized by crops. In this way, agroforestry can lead to successional development akin to natural ecological succession and mimic the large-scale patch dynamics and successional progression of a natural ecosystem (Ong and Leakey, 1999). Long-lived trees grown for their marketable products maximize these agroecological benefits, while also generating income and other benefits. So far, unrealized opportunities exist to understand how to create multistrata canopies composed of species producing useful and marketable products, which differ in height, form, growth habit, etc., and which could be grown in various different densities and configurations (Leakey, 1998b, 2014e). Such opportunities would also offer niches for conventional staple food crops bred for shady agroecosystems.

One component of soil health is attributed to its physical properties, as expressed by variations in soil depth, bulk density, aggregate stability, infiltration rates, hydraulic conductivity, water-holding capacity, and penetration resistance, time run-off, drainage, and penetrometer resistance, many of which are affected by the presence of organic matter and the turnover of fine root populations of plants, especially long-lived perennials like trees and shrubs, including fertilizer trees. For example, in Zimbabwe and Zambia leguminous fallows lowered soil bulk density by 12% and raised aggregate stability by 18–36% (Table 39.4). Likewise, pore density was raised from about 255 m^{-2} to 285–443 m^{-2}, and the pore density was greater, up from 2689–3938 m^{-2} to 4521–8911 m^{-2} (see review by Sileshi et al., 2014), attributable to larger pore sizes, up from 0.03 mm to 0.07−0.12 mm at 5 cm tension. Improvements in soil structure like these improve soil drainage by 42−600%, and reduce water run-off by 40−133%, which is especially important during wet periods (Table 39.4). Such changes in soil physical properties resulting from fertilizer trees improve water recharge, retention, storage, and availability to associated crops, while the tree canopies intercept rain and release it slowly to the soil, where it is available for crop growth with demonstrated improvements in water-use efficiency/rain-use efficiency in Africa (Sileshi et al., 2011).

Together with enhanced soil fertility, structure and function, all these benefits are important for the restoration of the biodiversity of soils, especially soil fauna—the decomposers, belowground micropredators and soil engineers (Sileshi et al., 2008b,c; Lavelle et al., 2014; Garbach et al., 2014) and the beneficial mycorrhizal fungi that have symbiotic associations with plants (Alexander and Lee, 2005). Gaining a thorough understanding of the complexity of agroecosystems function and their optimization in production systems that also improve livelihoods through approaches to agricultural intensification is probably the greatest challenge for scientific endeavor today (Leakey, 2014e). Progress is especially needed to gain a mechanistic understanding of the organisms, guilds, and ecological communities that provide ecosystem services together with quantitative measures of yield and ecosystem services in the same farming systems, especially at multiple scales (see review by Garbach et al., 2014). In this regard, considerable progress has been made in recent years to understand the categories and roles of the many different types of organisms that live in soils (see review by Lavelle et al., 2014). They classify them in five scales:

1. Microbial biofilms and colonies—occupying the smallest soil habitats found in assemblages of mineral and organic particles of approximately 20 mm in size
2. Micropredators such as nematodes and protoctists that feed on microbial biomass in meso-aggregates, at a scale of approximately 100−500 mm
3. Ecosystem engineers, such as earthworms, living at the scale of decimeters to decameters, which affect the architecture of soils through the accumulation of soil particles into aggregates separated by pores of different sizes. They can have important effects over scales ranging horizontally from decimeters to 20−30 m and vertically from a few centimeters up to a few meters in depth
4. Organisms occupying complex spatial domains such as community structures representing colonies of organisms, like termites and ants
5. Organisms occupying ecosystem and landscape mosaics.

The best practical examples of the agroecological impacts of crop diversification in Africa show that nitrogen-fixing legumes can lead to crops with lower susceptibility to weeds, pests, and diseases (Sileshi et al., 2014). For example, weed control results from shading and smothering aboveground and greater completion belowground, as in the case of the serious weed, Spear grass (*Imperata cylindrica*). Other important effects result from the release of allelochemical compounds that inhibit seed germination (Sileshi et al., 2014); or as in the special case of *Sesbania sesban* and the fodder legumes *Desmonium intortum* and *Desmonium uncinatum* which reduce populations of the parasitic weed of cereals, *Striga* spp., by stimulating "suicide germination" in the absence of the host (Khan et al., 2002). This is affected by the rate of decomposition and nitrogen mineralization of organic residues (Gacheru and Rao, 2001). With regard to pest control, in simple cereal/legume mixtures *Desmodium* spp. has been shown to act as repellents to the cereal stem borers *Busseola fusca* and *Chilo partellus*. On the other hand, Napier grass (*Pennisetum purpureum*), planted as an intercrop or around small fields, attracts the pests away from the crops (Khan et al., 2006; Cook et al., 2007). Thus, a secondary benefit of diversifying farming systems is the provision of habitat for ecologically important components of wildlife (Leakey, 2014e) that regulate pests and diseases. Consequently, by maintaining the "balance of nature," which is lost in monocultures, there is a reduced need for expensive pesticides to protect the crop artificially.

An agroecological approach to maintaining ecological health is therefore a good option for poor smallholder farmers as, without the need for financial expenditure, it sustains resilience to severe weather and other environmental hazards by enhancing the natural processes that maintain soil health. In addition, the noncrop components of the system can provide other useful, edible and marketable products (Leakey, 1999a; Jamnadass et al., 2011). However, on its own, attending to agroecological processes does not solve all the problems, because the lack of income for the purchase of inorganic fertilizers providing phosphorus and potassium salts and trace elements, as well as pesticides, remains a constraint to achieving the full biological potential of modern crop varieties (Leakey, 2010, 2013).

We argue that the multiple biological, ecological, social, economic, and environmental benefits arising from complex agroecosystems are the most important outcome of farm diversification through multicropping. It results in higher outputs from fewer inputs, with the added advantages of ecological resilience and risk aversion, i.e., greater efficiency (synonymous with total factor productivity). There are excellent examples of these diverse and productive mature agroecosystems in Southeast Asia (Leakey, 2001a) and Latin America (Schroth and do Socorro Souza da Mota, 2014), providing a model for Africa (Leakey, 2001b). In Africa, there is a wealth of traditionally important indigenous species providing food, medicinal and other useful products to create both the upper middle and lower strata of such complex systems (Abbiw, 1990; Vivien and Faure, 1996; Leakey, 1999a,b; Nono-Wombin et al., 2012; Awodoyin et al., 2015) that could be domesticated to fill different niches and make these systems highly productive. Multicropping is especially advantageous to smallholder farmers who have to produce all their household food and nonfood products without agrichemicals and with minimal risk of an ecological crash (Leakey, 1999b). Nevertheless, by providing habitat for all forms of local plants and animals, mature ecosystems are also a means of conserving wildlife and genetic resources (Atta-Krah et al., 2004) threatened by habitat loss and at the same time reduce the incidence of pest attacks (see reviews by Leakey, 2014e; Schroth and do Socorro Souza da Mota, 2014). These multiple biological, ecological, social, economic, and environmental benefits contrast with the common view, however, that there are "trade-offs" between production and wildlife conservation and ecosystem services (Godfray and Garnett, 2014). We concur with others who recognize that trade-offs are not inevitable (Maes et al., 2012) and that synergies can be achieved between ecosystem services and production (Nelson et al., 2009). Thus the compensation of farmers for adopting low-input farming systems by greater intensification elsewhere, or by the reallocation of land for biodiversity conservation and other environmental services (such as "set-aside" systems in Europe) is not needed in the tropics where smallholders have to provide all the food and nonfood needs of their families on 1−5 ha of degraded land. In some circumstances, however, payments for environmental services (PES) such as carbon sequestration by trees also meeting household needs for a range of tree products, may be an option (van Noordwijk et al., 2011).

Target 4: Domesticate and Improve Indigenous Species as New Crops for: (1) Better Nutrition and (2) Income Generation

Since the mid-1990s there has been a major research initiative to domesticate traditionally important, indigenous food and nonfood tree species for their nutritional, cultural and income generation benefits (Leakey et al., 2005a; Jamnadass et al., 2011); this initiative is now global (Leakey et al., 2012).

1. Nutrition:

   Modern approaches to agriculture have dramatically enhanced access to a small number of starch-based staple foods and this has allowed the growth of the human population to the current 7 billion. However, despite this success nearly half the world population still suffers from inadequate access to food (food insecurity) and from dietary deficiencies (nutritional insecurity). In contrast, the use and availability of traditional foods which were gathered from forests and woodlands or grown in home gardens have declined (Assogbadjo et al., 2012). Modern agriculture has focused on calorie production at the expense of micronutrient intake and dietary diversity—both elements of healthy living. Of special concern is the fact that about 80% of African farmers suffer hunger and malnutrition at some point in the year—the so-called hungry farmer paradox (FAO, WFP and IFAD, 2012; Bacon et al., 2015). These deficiencies in agriculture raise human rights issues regarding food sovereignty and rights of poor and marginalized people to food; to traditional knowledge and to the germplasm of traditional food species (de Schutter, 2011; Claeys, 2015).

   Malnutrition affects about 3 billion people due to dietary imbalance arising either from undernutrition in poor areas (2 billion), or overeating processed "fast" foods in rich areas (1 billion). To address this there are initiatives to use modern genetic techniques to fortify conventional staple foods with added vitamins (Nestel et al., 2006), but this overlooks the opportunity to also diversify and enrich farming systems with many traditional food species that are rich in vitamins, minerals and other micronutrients (Leakey, 1999a; van Damme and Termote, 2008; Nono-Wombin et al., 2012; Agoyi et al., 2014; Boedecker et al., 2014). This cultural approach has multiple benefits—sociocultural, agroecological, dietary, as well as for the enhanced health and well-being of rural households (Assogbadjo et al., 2012)—and is becoming recognized as an appropriate strategy for national and regional nutrition/health programs (Fungo, 2011). Consequently this approach to addressing the nutritional needs of malnourished people has many advantages over the genetic fortification of cereal crops.
2. Income

   Farm income in the tropics is typically acquired from the sale of cereals and other staple foods surplus to domestic household requirements, or by producing cash crops, generally for export. The domestication of indigenous trees offers several ways to enhance farm income, and so alleviating poverty as a constraint to purchasing agricultural inputs (fertilizers, pesticides, irrigation, better farm infrastructure, etc.). In addition to timber and wood for constructing numerous things, from housing to agricultural implements, trees produce foods (fruits, nuts, edible leaves and edible oils, etc.), medicines, extractives (resins, gums, latex, perfumes, dyes, tannins, etc.) and fibers for paper, crafts, baskets, etc., which are widely recognized for their usefulness as well as being sold in local markets (Abbiw, 1990; Vivien and Faure, 1996). For example, a cocoa farmer with 1.4 ha of land might have about 17 trees providing shade to the cocoa. If these trees are an indigenous fruit tree like *Dacryodes edulis* producing fruits worth \$20−\$150 per tree, depending on the characteristics of the individual trees, the farmer can make an additional income of about \$700 from these fruits in the local market. Evidence from Nigeria, however, has shown that the average annual income from the sale of products from 100 trees of each of three species (*Chrysophyllum albidum, Irvingia gabonensis* and *Garcinia kola*) across 10 villages ranged from \$US300 to \$US1300 and that this contributed 20−60% of annual family income (Onyekwelu et al., 2014). In Cameroon, the kernels of another fruit (*Ricinodendron heudelotii*) contributed 12−15% of household cash generation (Cosyns et al., 2011).

Remembering that over 70% of the population of very large parts of Africa live on less than \$1.25 per day (Sebastian, 2014), it is important to appreciate that even small increases in income from tree products can be very important to the livelihoods of rural households. Thus, for example, sums of only \$50 to \$100 from tree products (e.g., Ayuk et al., 1999a,b; Schreckenberg et al., 2006; Shackleton and Shackleton, 2005; Shackleton et al., 2011) have real significance for expenditures on food, medicines, clothing, schooling, farm inputs, etc. Typically, women are the traders in these tree products and the income derived from them is spent on the needs of the household and the children.

In addition to the sale of raw products on local markets, communities engaged in tree domestication are also generating income from the sale of plants to neighbors and other communities. For example, in this way, communities in Cameroon have built up to an annual income of over \$28,000 after 10 years (Asaah et al., 2011; Leakey and Asaah, 2013).

Despite the existence of local markets for tree products, farmers do not receive good prices because of dysfunctional value chains (Ingram et al., 2015), poor infrastructure, limited market information, inadequate processing and storage methods, poor product quality, and lack of uniformity, etc. (Facheux et al., 2006, 2007). To address these issues and maximize and ensure the sustainability of income benefits, domestication has to go hand in hand with commercialization (Leakey and Izac, 1996) to take advantage of any complementarities (Degrande et al., 2014). The role of domestication becomes increasingly important as the products progress up the value chain because the more formal regional and especially international markets insist on the quality and uniformity of products, as well as the regularity of supply (Leakey and van Damme, 2014). Evidence suggests that the greatest benefits are derived when production, harvest and postharvest interventions are linked with activities that promote the effectiveness of local organizations and policies to support the commercialization process (Degrande et al., 2014). Product uniformity has also been found to be important

FIGURE 39.2 Safou (*Dacryodes edulis*) fruits in Cameroon. Consumers recognize and are willing to pay for desirable traits—more than just size and color.

in local wholesale trade of *D. edulis* fruits in Cameroon if farmers are to obtain a price greater than that paid for the typical mixture of wild fruits (Leakey et al., 2002). In the retail trade, however, stall holders sell small collections of uniform fruits at different prices, depending on consumer preferences (Fig. 39.2).

Tree nuts often have another inherent constraint to marketing: they are difficult and/or laborious to crack without damaging the kernels—e.g., *I. gabonensis, R. heudelotii, Sclerocarya birrea*. This poses a disincentive to engage in trade, which is now being addressed by the development of simple nut crackers, which are showing promise especially to enhance economic advantages for women (Mbosso et al., 2015). They increase returns to labor and are increasing the number of trees that a household can grow and harvest.

To help farmers generate more income from the sales of AFTPs, linkages and partnerships between producers and traders are being developed by promoting group sales, thus pooling resources such as credit, information, transportation, and labor (Facheux et al., 2012). Despite initial low levels of trust between the AFTP producers and traders, both actors were committed to continue the alliance for strategic reasons such as increased negotiation power, share production and market information, and gain from capacity-building programs (Foundjem-Tita et al., 2011) and reduced transaction costs (Foundjem-Tita et al., 2012a). In another initiative the facilitation of a village-level stabilization fund for better storage methods to promote off-season sales found that the coupling of improved storage and guarantee funds helps enhance farmers' capacity to capture higher prices (Facheux et al., 2012). However, the lower cost of group sales was found to be a better starting point for group interventions.

In general there is not much processing or value adding yet done for these traditional food products, but it has been demonstrated that there is great opportunity to increase the income-generation opportunities by simple drying, packaging, etc. in "cottage" industries (Asaah et al., 2011). This will extend the shelf life, allowing the expansion of markets both geographically and into the off-season period (Leakey, 2012b; Leakey and van Damme, 2014). Indeed, the long-term potential is even greater as many tree products are used in international pharmaceutical, cosmetic, nutraceutical, and in food and beverage industries, and even in car manufacture (Leakey, 2012b). This is an area for future expansion as the domestication process progresses (Leakey et al., 2012). This process will be enhanced if the relevant industries interact with those engaged in the domestication, so that the selection process is driven by the needs of the industry (Leakey, 1999a), based on identification of relevant ideotypes (Leakey and Page, 2006) which, through genetic selection processes, can make use of the three- to tenfold tree-to-tree variation to tease out different strands from the wild resource to create cultivars as different from each other as are the breeds of dogs that have been derived from the wolf (Leakey, 2012b).

Throughout the tropics and subtropics, traditional markets selling local products are essential to the everyday life of people, both vendors and consumers. Nevertheless, these informal markets are seldom recognized in national statistics or policies. However, in recent years, wider recognition of the potential and importance is growing (Beattie et al., 2005; Shackleton et al., 2000; Jamnadass et al., 2010), local processing and value addition are being initiated, (Bille et al., 2013) and new tree products are entering commerce: e.g., baobab fruit and leaf (www.phytotrade.com/products/baobab; www.aduna.com; www.theafricanchef.com); marula fruits and kernel oils (www.phytotrade.com/products/marula; www.wildfruitsofafrica.com); and alcoholic beverages (www.amarula.com) and "Becel" margarine from Allanblackia kernel oil (www.allanblackiapartners.org).

While there is evidence that farmers in Africa (Leakey et al., 2004, 2005b,c) and other continents (Parker et al., 2010) have initiated their own domestication processes for indigenous fruit trees, these have not had the benefits of a scientific approach. To progress this enterprise, there is now a global research program to assist poor farmers to domesticate traditional food and nonfood species and address the needs for better nutrition and greater income (Simons, 1996; Kengue et al., 2002; Akinnifesi et al., 2008; Ræbild et al., 2011; Leakey et al., 2012). The idea behind this initiative arose from discussions with farmers in the 1990s about what they would like to see from agriculture (Franzel et al., 1996, 2008). They indicated that they would like to cultivate the indigenous food tree species that produce products that rural people used to gather from forests and woodlands. A participatory approach is being implemented (Tchoundjeu et al. 2002, 2006, 2010; Asaah et al., 2011) to ensure that farmers are the beneficiaries of this work. The program is based around rural resource centers (RRCs) which assist smallholder farmers with access to resources of indigenous trees to identify elite individuals meeting the domestic food or other day-to-day needs of the household (Tchoundjeu et al., 2006; Takoutsing et al., 2014) and to develop these as cultivars. Many of the products of these trees also have potential to be marketed locally or regionally. Using simple, low-cost horticultural techniques these elite trees are then propagated vegetatively (Leakey et al., 1990) from juvenile or mature tissues, as appropriate, either on-farm or within the village (Leakey and Akinnifesi, 2008). The resulting plants are then out-planted in farming systems so that the benefits accrue directly to the farmer. Contrary to the slow process of tree breeding, this horticultural strategy results in superior cultivars that start to produce fruits or other products within 2–3 years (Leakey and Simons, 1998; Leakey and Akinnifesi, 2008).

The domestication process requires multidisciplinary research inputs (strategies and techniques) to capture and make the best use of the genetic variation present in wild populations; to make certain that the process is sustainable and adoptable;

TABLE 39.5 Multidisciplinary topics studied in Cameroon to develop effective participatory tree domestication within an agroforestry approach to deliver multifunctional agriculture.

Topics	References
Strategy for participatory involvement of communities	Leakey et al. (2003), Tchoundjeu et al. (2010)
Techniques and domestication strategy	Leakey and Akinnifesi (2008)
Farmer livelihood strategies	Degrande et al. (2006)
Characterization of intraspecific variation	Atangana et al. (2001, 2002), Waruhiu et al. (2004), Anegbeh et al. (2003, 2005)
Genetic molecular characterization	Lowe et al. (2000), Muchugi et al. (2008), Assogbadjo et al. (2009), Jamnadass et al. (2009), Mwase et al. (2010)
Sensory evaluation	Kengni et al. (2001)
Genetic resource management	Dawson et al. (2014)
Selection of trees well adapted to climate change	Weber et al. (2008, 2015), Weber and Sotelo Montes (2010), Sotelo Montes and Weber (2009), Sotelo Montes et al. (2011)
Horticultural protocols	Leakey et al. (1990), Leakey (2014c)
Root systems	Asaah et al. (2010, 2012)
Community constraints and benefits	Schreckenberg et al. (2002), Degrande et al. (2012)
Policy	Leakey and Tomich (1999), Simons and Leakey (2004)
National forest laws	Foundjem-Tita et al. (2012b)
Impact	Degrande et al. (2012), Asaah et al. (2011), Leakey and Asaah (2013)
Trade, marketing, and industry development	Jamnadass et al. (2010, 2014), Leakey et al. (2012), Leakey and van Damme (2014)

and to ensure that it has beneficial social and economic outputs and impacts for the growers and local traders (see review by Leakey, 2014a). Research at the World Agroforestry Center and its partners over the last 22 years to develop this participatory approach to tree domestication implemented in the villages by the farmers (Tchoundjeu et al., 2006, 2010; Asaah et al., 2011, Degrande et al., 2006, 2012) has been multidisciplinary and addressed many transdisciplinary issues (Table 39.5). It has achieved many positive impacts, with farmers saying that their lives have been transformed (Asaah et al., 2011, Leakey and Asaah, 2013) as they now have more food, better and more diverse diets, and are healthier.

The participatory approach employed by this multifaceted program is delivering a wide array of social, economic and livelihood benefits (Leakey, 2014a) and avoids concerns about the loss of genetic diversity, as about 70–80% of the intraspecific variation found at the village-level (de Smedt et al., 2011; Pauku et al., 2010) decentralized domestication in scattered villages has the benefit that it allows the capture of elite individuals at each location without seriously narrowing the genetic diversity of the species (Leakey, 2012b). Nevertheless, there are important issues still to be addressed, such as how to create equitable partnerships between producers and entrepreneurs to ensure that the farmers' innovations and cultivars are protected from unscrupulous entrepreneurs (Laird, 2002). Toward this end, interim interventions have been initiated (Lombard and Leakey, 2010) and work is in progress to promote new approaches to protecting the intellectual property of African farmers engaged in participatory tree domestication (Santilli, 2015).

Earlier we recognized that, unlike the situation in industrialized countries where typically less than 1% of the population is engaged in farming, the proportion in developing countries can be more than 75%, each with only a small area of land to provide all the food and other needs of the family. Breaking this demographic scenario is crucial to rural development, especially in Africa. Thus the creation of a pathway out of poverty through the development of new, off-farm, income-generation opportunities for farming households has to be part of the concept of sustainable intensification (Leakey, 2012a)—an outcome that also offers the opportunity to engage in microfinance schemes (Asaah et al., 2011). Experience in Cameroon has shown that developing diversified farming systems, which produce traditional tree food products for local markets, is having numerous positive outcomes and impacts on the livelihoods of participating communities (Tchoundjeu et al., 2010; Asaah et al., 2011; Leakey and Asaah, 2013; Degrande et al., 2014), and

TABLE 39.6 The local level cascade of expected outputs and outcomes from implementing agroforestry to deliver multifunctional agriculture. Thirty-two of these outcomes have already been reported (Tchoundjeu et al., 2010; Asaah et al., 2011; Degrande et al., 2014; Leakey, 2014a).

Intervention → Impacts				
	Results	**Outputs**	**Outcomes**	**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 agrobiodiversity 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	Beekeeping for honey production	Income generation and improved dietary health
	• Production of fuel wood	Reduced labor 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 agrobiodiversity 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
			• Postharvest processing for wider trade year-round	Income generation
	• Establish participatory domestication process	Community engagement in rural resource centers	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

(*Continued*)

TABLE 39.6 (Continued)

Intervention → Impacts	Results	Outputs	Outcomes	Impact
	• 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	Postharvest 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

creating hope and optimism (Table 39.6). Indeed, in parallel with these developments, small cottage industries are emerging in which tree and other farm products are being processed, packaged (Asaah et al., 2011, Mbosso et al., 2015) and traded. Value adding in this way is extending the shelf life of tree products, such as the leaves of *Gnetum africanum* and kernels of *R. heudelotii*, expanding the season, and opening up new and more distant markets.

Interestingly, with the decline of former plantation systems for many cash crops, such as those for cocoa, tea, coffee, and rubber, smallholder farmers are developing innovative smallholder agroforestry systems based on complex species mixtures that include cash crops, as illustrated by cocoa grown under indigenous fruit trees instead of unproductive shade trees (Leakey and Tchoundjeu, 2001). Extending these concepts further, opportunities are now arising for local communities engaged in these approaches to produce a range of different tree products in multistrata farming systems—a Win:Win situation (Leakey, 2001a,b). Furthermore, this can be extended with the foundation of larger scale public–private partnerships with innovative and progressive multinational companies (Jamnadass et al., 2010, 2014; Leakey, 2012b). As mentioned earlier (Chapter 32 [Leakey, 2017f]) this initiative can be considered as the 'social modification of useful organisms' existing wild genetic resources by community-based organizations.

In recent years there has been growing interest in traditional food crops and neglected and underutilized species, as is evident from international conferences in Tanzania (2008), Malaysia (2011), Ghana (2013), and Senegal (2014). Together these developments indicate that there is now a need for policies that give greater recognition to the value of underutilized species as producers of nutritious traditional foods when cultivated as new crops for their health benefits, as well as being important components of the ecology of farming systems, which additionally sequester carbon for the mitigation of climate change. Unfortunately, in many tropical countries policies to reduce deforestation by reduced exploitation of forest trees have not differentiated between timber and nontimber forest products (fruits, nuts, leaf, fiber, bark, extractives, etc.) many of which are now gathered from farmland rather than from natural forests and woodlands. Making the sale of nontimber products illegal regardless of their origin provides a strong disincentive for farmers to diversify their cropping systems with local species (Foundjem-Tita et al., 2012b). As a consequence, it has been suggested that terms like "non-timber forest products" should only be applied to common-property forest resources and that "agroforestry tree products" be used to refer to private-property products from farmland (Simons and Leakey, 2004).

Target 5: Close the Yield Gap by Addressing Local Supply Side and Livelihood Problems

As mentioned earlier, the difference between potential yield and actual yield in staple food crops—the yield gap—is the result of the cycle of land degradation and social deprivation (Fig. 39.1), a linked set of complex environmental, social, and economic factors associated with: (1) environmental degradation, (2) a lack of access to natural resources (Ellis and Allison, 2004), and (3) poverty (Tittonell and Giller, 2012). Consequently, the solution goes beyond agronomic interventions and we see a need to adopt an integrated approach to addressing Targets 1, 2, 3, and 4. This is because poor soil fertility, low crop productivity and agroecosystem health, and a lack of income all interact to cause a dysfunctional relationship which, in turn, results from a failure to recognize that there are social and environmental constraints that hinder the adoption of the Green Revolution package of technologies in Africa. As a consequence, unlike temperate agriculture, modern technologies are failing to deliver food security, public health, and wealth creation.

Practical steps to close this yield gap have been proposed by Leakey (2010, 2012b):

Step 1. Adopt 2–3 year improved fallows or relay cropping with leguminous trees and shrubs to restore soil nitrogen fertility—see Target 2—and raise crop yields two- to threefold and so lead to about 50% closure of a yield gap. This also initiates the improvement of soil health (see Target 3). The development of village tree nurseries additionally creates income-generation opportunities. Likewise, income from stakes, fuelwood, livestock, and bee fodder importantly offset any crop yield losses due to tree/crop competition, as well as compensating for any extra labor demand for planting high density tree fallows. These leguminous trees and shrubs also have beneficial agroecological impacts (Target 3).

Step 2. Initiate and adopt the domestication of trees producing nutritious traditional foods (as well as other marketable products such as medicines, essential oils and other extractives, and fuelwoods with high calorific value) for domestic consumption as well as to generate income for the purchase of agricultural inputs and for infrastructure improvements. This step also creates new business and employment opportunities in new rural industries (see Target 4). This also further improves agroecosystem functions (see Target 3). Such diversified and intensified cash cropping systems combine production with ecosystem services and biodiversity conservation (Leakey, 2014e; Cerda et al., 2014), while diversifying income and enhancing food security (Fouladbash and Currie, 2015). Within this step, the domestication of nutritious fodder trees can enhance livestock components of mixed farming systems. The cultivation of new socially-modified tree crops also has the advantage of increasing sinks for greenhouse gases and the consequent mitigation of climate change.

Step 3. Promote entrepreneurism for the expansion of marketing, trade, value adding and processing of traditional and other food and nonfood products to further stimulate income generation and value chain development (see Target 4) to allow rural communities to expand cottage industries.

Smallholder access to markets for higher-value or differentiated agricultural and food products is a vital opportunity for lower-income farm households to improve their cash incomes and food security by shifting their livelihoods from low-value commodities to fruits, vegetables, milk, and other high-value products (World Bank, 2007). Jaffee et al. (2011) have pointed out that constraints related to basic infrastructure, farmer organizations, access to finance, etc. remain as barriers to smallholders' participation in markets linked to value chains. Interestingly, an evaluation of the impact of value chain interventions to lessen these constraints on the commercialization of kola nuts (*G. kola*) in Cameroon found benefits to farmers' livelihoods arising from substantial cost reduction, improved market information, strengthened bargaining position, and improved product conservation (Ferket, 2012; Gyau et al., 2012). Together these led to higher selling prices and increased the average household income from kola as well as its contribution to total income. These benefits spilled over to others in the villages across all wealth classes. However, it is evident that value-chain constraints differ from product to product and country to country, and arise from differences in product collection techniques, postharvest pest infestations, storage techniques, etc. Thus the first step in value-chain development should be a diagnosis of the specific issues (Degrande et al., 2014). Nevertheless, improvements introduced across the value chain have substantial benefits to the livelihoods of rural households.

One logical, but perhaps unanticipated benefit of using the income from the sale of products from trees integrated into farming systems to purchase inputs like fertilizers to intensify food crop production and close the cereal yield gap is that the cultivation of the land and the application of inputs such as fertilizers have additional production impacts through the increased yield of tree products (Khasanah et al., 2015). In South Africa, for example, wild marula (*S. birrea*) trees in natural vegetation only produced an average of 3200−6500 fruits, while those growing in farmers' cultivated fields produced 17,000−115,000 fruits (Shackleton et al., 2003). This indicates that total production per hectare can even exceed that achieved by closing the cereal yield gap.

Overgrazing by livestock has been one of the contributing factors to land degradation, especially around water holes in dry areas. We see opportunities to integrate fodder trees for small-scale livestock and fish more effectively into the farming system as a valuable source of protein and income, in combination with their already mentioned ecosystem and nitrogen-fixing benefits. Trees producing fodder for livestock have many livelihood benefits, including the provision of meat, milk and other useful products for better human nutrition, income generation and general utility (see review by Franzel et al., 2014). In Africa, farmers typically plant locally adapted fodder trees in a wide range of on-farm niches that minimize the loss of space for staple food crops. Fodder is often harvested and fed to tethered or stall-fed livestock, especially during the dry season when herbaceous fodder resources are limited. Yields vary depending on the tree species and the site (see review by Franzel et al., 2014). For reasons of digestibility, it is generally recommended that tree leaf fodder should be 15−30% of the diet. Thus in East Africa, a farmer needs about 500 regularly cut-back trees to feed a dairy cow 2 kg of dry matter per day throughout the year. This equates to approximately 1 kg of dairy meal, and produces about 0.6−0.75 kg milk per kilogram of fodder. Mean net returns from four sites over 2 years in Kenya and Uganda from 500 trees ranged from US$30 to US$114 per year (Wambugu et al., 2006, 2011). In the future, if the yield gap is closed on a large-scale and maize yield increased from 1−2 to 7−8 tonnes per hectare, surplus grains could be used to further enhance the opportunities for livestock and fish production. While we recognize that the suggestion to moderate demand for resource-intensive foods like meat and dairy as a component of sustainable intensification (Garnett et al., 2013) may be appropriate in industrialized countries, we believe that the opportunity for small-scale and more sustainable livestock production in Africa is important for people's livelihoods. However, there is an issue regarding the need for support by extension services. Although fodder trees require relatively little land, labor, or capital, farmers need specialist skills and knowledge for wider adoption (Franzel et al., 2014).

Target 6: Provide Training in Rural Communities to Enhance Their Capacity to Implement Technologies Relevant to Sustainable Intensification

The circumstances of poor smallholder farmers in Africa have often prevented them from having the opportunity to gain more than a basic education. This situation has also been exacerbated by the reduction of funds to support agricultural extension services which used to provide practical training in farming techniques. This has serious implications for agricultural development and especially the introduction of new skills, knowledge and understanding to enhance the productivity and sustainability of farms. Women in Africa are in special need of interventions to ease their burden in farming systems (Kwamina et al., 2015). Several approaches to agroforestry ease the burden of women and are ready for upscaling, having demonstrated their potential for wider adoption and indicated some important characteristics that encourage adoption: a farmer-centered approach, provision of a range of options for farmers, building local capacity, sharing knowledge and information, learning from experience and the development of strategic partnerships through facilitation activities

(Franzel et al., 2004; Kiptot and Franzel, 2015). Issues around access and rights to land can, however, be a problem under some circumstances (Schreckenberg et al., 2002, Gyau et al., 2014).

In association with the implementation of interventions to address Targets 2, 3, 4, and 5, in Cameroon, the concept of RRCs evolved as a partnership between researchers and relay organizations (local NGOs and CBOs that lead the extension program) (Tchoundjeu et al., 2006, 2010; Degrande et al., 2014), to reconcile the needs of farmers with research (Takoutsing et al., 2014). Initially, the RRCs focused on community tree nursery establishment and management for the production of nitrogen-fixing trees and shrubs and their planting in farming systems. These nurseries then expanded into simple tree domestication techniques (elite tree selection, genotype capture, cultivar multiplication by vegetative propagation, and stockplant management). Over the early years this program has involved bottom-up, farmer-to-farmer dissemination so that the number of participating farmers has "snowballed" as RRCs developing satellite tree nurseries servicing neighboring communities (Tchoundjeu et al., 2006, 2010). The media, intervillage competitions and local fairs have been used to publicize the program. In this way, over 12 years, the program has grown from 10 farmers in two villages to about 10,000 farmers in 500 villages over the North and Northwest provinces (Asaah et al., 2011; Degrande et al., 2012).

As this program has grown, so the activities of the RRCs and relay organizations have evolved and expanded to provide new skills and knowledge through the further evolution of the training programs. This has led to the availability of microfinance, marketing, product processing and value adding, community management committees for infrastructure developments, and enhanced trade (Asaah et al., 2011), spawning new opportunities for income generation and employment in the wider community. One role of the relay organizations as "diffusion hubs" is to gather production and market information and to build linkages between farmers and traders so as to facilitate price negotiations. By 2012 a market information system had been developed in Cameroon, which extended in DR Congo, for five tree products spanning 99 producer groups and 71 traders. Evidence showed that, to the satisfaction of both producers and traders, this system was creating awareness of the supply of products and their quality, the current market prices, and the opportunities for transportation (Degrande et al., 2014). In addition, capacity-building sessions have reinforced and strengthened social assets and coherence among villagers by forging new relationships among producers as part of the value chains (Cosyns et al., 2013).

In conclusion, community-based RRCs have been found to be effective as a means to enhance a self-help philosophy for agricultural development with socially-modified organizations (Asaah et al., 2011; Degrande et al., 2012) and are being found to greatly increase well-being: health, opportunity, social justice, equity, enhanced self-sufficiency, and empowerment (Tchoundjeu et al., 2010; Asaah et al., 2011). Thus, for the future they provide a replacement for former national extension services (Franzel et al., 2014), which have been in decline for several decades.

Target 7: Achieve Energy Security Without Environmental Damage

While there are many new and emerging energy technologies from solar, wind and water power, currently about 2.7 billion people depend on woody biomass as fuel for cooking and other uses (WHO, 2014), mostly gathered, unsustainably, from natural vegetation. This fuel wood gathering is one of the drivers of forest and woodland destruction and land degradation, and is closely associated with poverty, hunger, and malnutrition, as well as health issues from inhaling wood smoke. As wood becomes more scarce, women and children have to spend more time and effort gathering it, or make or purchase charcoal. The use of charcoal, often transported long distances, is also on the increase, especially in urban areas. In parallel, simple but more efficient solid-fuel cookers are being increasingly used.

While the cultivation of trees in woodlots as a source of fuel is possible, many families must spend their time and effort to grow food. Nevertheless, trees of many species can be used for fuel wood and thus an agricultural system diversified with trees for soil fertility enrichment, animal and bee fodder, fruits, nuts, and medicines affords the opportunity to use dead wood as a byproduct of farming. In addition, approaches to bioenergy production are becoming an important opportunity for farmers as part of a strategy for clean and sustainable energy source (ICRAF, 2015). For example, wood from agroforestry systems can be used for charcoal production, the development of liquid biofuels and for electricity generation, so creating more renewable sources of bioenergy. In addition, there are opportunities to enhance the fuel quality of wood in terms of its density and calorific value (Sotelo Montes and Weber, 2009; Sotelo Montes et al., 2011). Provision of fuel wood in these ways is much more sustainable than gathering it from natural forests and woodlands.

Target 8: Reduce and Eliminate Waste

In industrial countries food wastage from supermarkets, shops, restaurants and homes is serious (Garnett et al. 2013) and needs to be reduced by changes in patterns of consumption and better market planning. However, in contrast, in developing countries, where food is scarce, the main issues in food wastage are: postharvest losses of raw products due to contamination, rotting and decomposition, and pest attacks. These arise from poor storage and drying facilities for food products and techniques, and inadequate transport infrastructure. The resolution of these issues is constrained by lack of income for village storage infrastructures and facilities. Consequently, there are strong linkages here with Targets 4 and 5 aimed at income generation and the evolution of businesses engaged in food processing and value adding (Asaah et al., 2011; Degrande et al., 2014).

Target 9: Promote Integrated Livestock Management in Drylands and Animal Welfare

Approximately 1 billion head of livestock are held by more than 600 million poor smallholders, comprising approximately 70% of the world's rural poor (IFAD, 2004). Many of these animals are found in the African drylands where nomadic herdsmen use their local knowledge to move their flocks of goats and herds of cattle around areas with natural pasture and waterholes, as has been happening for generations. Probably the biggest issue here is the increasing size of these herds and the degradation of traditional grazing lands, especially close to watering holes. Consequently, sustainable intensification has to be about increasing the availability of feed and fodder, and in worst-case scenarios, the maintenance of wells and water resources to avoid starvation and dehydration, especially in the dry season. As in parts of the Sahel, this problem can raise quite complex social issues in order to avoid confrontation between the resident sedentary farmers growing cereals like sorghum and millet, and the nomads. Customary laws often give the farmers exclusive land rights in the cropping season, but in the dry season nomadic herdsmen often have the right to let their animals graze anywhere (Barrow, 1996). This results in a disincentive for farmers to grow perennial crops or to have irrigated vegetable gardens near wells, as these are likely to be browsed by livestock. Furthermore, as the stock of natural trees is depleted by the need for fuel wood, the tree resource of a wide range of both tree fodder and nonfodder products is threatened by the problems of their regeneration. The serious knock-on environmental effects of overgrazing can increase wind erosion, and they also pose a threat to the availability of species like baobab, which produces nutritious fruits and leaves for human consumption (Leakey, 1999a), as well as bark fibers. Worse still, there is some evidence that the absence of trees to draw nutrients from the lower strata of the soil and to deposit and recycle them as leaf litter on the soil surface is resulting in a downward nutrient pulse that threatens the potability of groundwater through nitrate toxicity (Edmunds and Gaye, 1997). This could have very serious future implications for both humans and livestock dependent on aquifers for their water supply. All of these issues make the deliberate cultivation of tree fodder an important component of tropical agriculture (Franzel et al., 2014). These trees, whether for fodder or other products, would also draw deep nitrogen back to the soil surface.

As seen earlier (Target 5), there is great potential to domesticate trees producing leaves important for livestock fodder (Franzel et al., 2014), as well as human food (Leakey, 2012b). Critically, however, the survival of these young trees depends on their protection from roaming livestock by the establishment of thorny hedges or overenclosures. Such actions to exclude livestock have the potential to bring the sedentary farmers into conflict with the herdsmen (Leakey, 2012b). On the other hand, if sedentary farmers were to produce fodder banks of indigenous trees with edible leaves for herdsmen and their livestock in exchange for money or animal products, then mutual benefits may allow the intensification of these drylands, and also reduce the environmental risks of overgrazing. Tree planting is not the only way to improve the resource of local trees in dry areas, as farmer-managed natural regeneration, through the exclusion of animals while young trees grow to a size that saves them from browsing animals, is also very successful and is now happening on a significant scale (Haglund et al., 2011) with numerous socioeconomic and environmental benefits (Weston et al., 2015). This too, however, involves the evolution of new relationships between farmers and nomadic herdsmen.

The elimination of animal cruelty has been identified as one component of sustainable intensification (Garnett et al., 2013). Although not absent from developing countries, intensive factory farming is more an issue in industrialized countries. In the rural tropics, livestock holdings per farm are typically just a few animals close to the household. In some cases, for example in the African Highlands, these animals are penned and fed by "cut and carry" systems where cruelty may happen, but in general this is not common, as the well-being of these animals is typically very important to the household's own livelihoods.

Target 10: Maintain Landscape Functions

The scale and spatial diversity of landscapes create diverse microenvironments that provide niches for many organisms, as well as physical formations appropriate for agricultural production and the protection and management of natural resources and public goods, such as watershed management or the conservation of biodiversity and genetic resources (Leakey, 1999b; Dawson et al., 2014), aided by remote sensing and geographic information systems.

Currently, there is growing recognition that sustainability, and hence sustainable intensification, is not just a phenomenon of importance at the plot or field scale, and that landscapes aggregate and integrate the range of outcomes at smaller scales in ways that actually provide a more meaningful expression of the state of natural capital and the ecosystem services that regulate them. Furthermore, the benefits of healthy landscapes can be greater than the sum of the smaller scales. As a consequence, landscape management has promising potential to reshape the processes and governance systems affecting land-use by individuals and by society at local, national, and global scales (Scherr et al., 2014; Minang et al., 2015). However, there is a need for much more evidence of the impacts of landscape-scale interventions with regard to farming practices and the level of intensification over time. In addition, there is a need to better understand how local agricultural decision making takes place in reaction to macrolevel economic and price dynamics, especially vis à vis the role of incentives and investments to enhance synergistic interventions across a multifunctional landscape (Scherr et al., 2014; Minang et al., 2015).

Multifunctionality is reflected in the ability of landscapes to provide services that are not normally traded, such as genetic conservation, carbon capture, pollination, and other ecosystem or environmental services (Torquebiau et al., 2013). In development, the integration of these different land-uses is often easier at larger scales. However, it is important to recognize that landscapes are dynamic and constantly changing and indeed can be either degrading or rejuvenating. Thus, at least five classes of landscapes can be appreciated:

- Pristine landscapes (very rare)
- Stable landscapes being effectively managed for production and environmental services
- Senile landscapes (progressing toward degradation: scale 10 − 1)
- Degraded landscapes that are neither productive nor ecologically/environmentally viable
- Rejuvenated landscapes that are being/have been rehabilitated (scale 1−10).

One of the complicating factors is that some senile landscapes can look much better than rejuvenated landscapes. However, the important point is that they are traveling in different directions.

It is at the scale of landscapes and the mosaics within them that we can begin to understand the aggregated effects of the environmental services on the sustainability of smallholder agriculture, which typically exceed the sum of their parts, providing positive multifunctional outcomes spanning agricultural production (food, wood, medicines, etc.), ecosystem and biodiversity conservation, human livelihoods and institutional planning and coordination (Estrada-Carmona et al., 2014), such as public policy and collective action initiatives like infrastructure developments shaping the relationship between society and the environment (Wu, 2013). Landscape approaches are also recommended to identify synergies between competing land uses or to link local initiatives with national and regional policies (Yaap and Campbell, 2012), as well as to reconcile conservation and developmental trade-offs (Peng et al., 2011; Sayer et al., 2013). Work in South Africa has found that, by characterizing landscape performance, it is possible to develop integrated solutions that effectively promote the multiple use of land (Torquebiau et al., 2013). It is important to recognize that the failure to maintain many of these landscape functions can have impacts at both ends of a transect. As an illustrative example regarding groundwater resources, the failure to match the yield potential of the relevant source landscapes to their rural and urban usage has negative impacts for rural and urban communities (MacDonald et al., 2012).

The delivery of the ecological, social, and economic landscape functions is subject to scale effects, history dependence, multiple interactions, nonlinear effects and uncertainty, all of which call for special management attention (Scott, 1998; Walker et al., 2004), such as the use of finance and stakeholder reward schemes for the ecosystem services (PES/RES) that simplify the management of landscape functions (van Noordwijk, et al., 2012). The term *socioecological production landscapes* refers to fostering human well-being, biodiversity, and ecosystem services (Gu and Subramanian, 2012) simultaneously managed at multiple nested scales and levels (Cash et al., 2006). To ignore the challenge of biologically rich farming systems that are both resilient and supporting farmers' livelihoods is to fail to address the real-world complexity of landscape functions and their externalities caused by high-input intensification (Jackson et al., 2012; Tscharntke et al., 2012). This is likely true in many landscapes, but Phalan et al. (2011) have shown that it is unlikely that landscapes can fulfill all use functions and deliver the desired ecosystem services; it will

TABLE 39.7 The landscape and global level cascade of expected outputs and outcomes from implementing agroforestry to deliver Multifunctional Agriculture.

Intervention → Impacts				
	Results	**Outputs**	**Outcomes**	**Impact**
Up-scaling of Steps 1–3 for landscape and global benefits	**Develop land-use mosaics and biodiversity corridors**	**Conserve biodiversity by expanding food webs and life cycle functions**	**Greater resilience to ecological and environmental shocks**	**Sustainable land-use**
			• Integrated pest management to reduce crop and livestock failure	Enhanced food security
		• Protect watershed functions	Maintain groundwater resources	Support rural, urban and industrial water use
		• Increased carbon sequestration in perennial plants and in soils	Mitigation of and adaptation to greenhouse gas emissions	Reduced global climate change
	• Enhance access to finance	Expand supply of products	Create business opportunities and meet customer needs	Income generation, well-being, food security and economic sustainability
	• Enhance access to markets	Expand demand for products	Create business opportunities and employment	Income generation and enhanced food security
	• Enhance access to farmer cooperatives, training schools, credit associations, stakeholder reward schemes, etc.	Expand capacity to innovate, manage and implement better land-use systems	Greater productivity, social collaboration and cohesion; community coordination and well-being	Improved food security, poverty alleviation, social equity and empowerment; and environmental resilience and sustainability
	• Expand involvement of certification schemes	Stakeholder incentives to practice more sustainable practices	Enhance rewards for rural populations	Improved environmental, social, and economic sustainability
	• Enhance access to remote sensing, information systems and communication systems	Better management of resources	Greater productivity, social collaboration and cohesion; community coordination and well-being	Improved environmental, social, and economic sustainability
	• Expand global awareness initiatives for greater environmental, social, and economic sustainability	Greater understanding of global issues and ways of addressing them	Acceptance of need for new initiatives to address sustainability of production systems	Public awareness and agreement with sustainable approaches to the intensification of agriculture
	• Improve global policies for greater environmental, social, and economic sustainability in agriculture	Agree on new approaches to agricultural intensification that enhance production without depleting natural resources	Implementation of new approaches to intensive agriculture that ensure food security and land rehabilitation, as well as personal, national and global economic development	A world more in tune with the needs to meet the sustainable use of natural resources while supporting a growing population

be necessary in some cases to prioritize some uses over others, and especially to consider conservation uses, in order to deliver the required ecosystem services. Nevertheless, experience suggests that many desirable outputs, outcomes and impacts are possible (Table 39.7). Indeed, by restoring the productivity of degraded land it should be possible to reduce the pressures to clear forests and woodlands for agriculture.

Recently debate has focused on "climate-smart agriculture" as an approach to concurrently produce food, conserve ecosystem services, enhance agroecosystem resilience and mitigate climate change by the reduction of greenhouse gas emissions from livestock, rice paddies, and soil denitrification (van Noordwijk, 2014; Rosenstock et al., 2015; Minang et al., 2015). This multifunctional concept in which trees in agricultural landscapes play an important role (van Noordwijk et al., 2011) has some similarities to that for sustainable intensification being described here.

Many opportunities to address climate change issues occur at the landscape level. Landscape approaches present opportunities for sustainable development by enhancing opportunities for synergy between many social, economic, and environmental objectives in landscapes (Minang et al., 2012, 2015). Together these seek to recognize the importance of landscape functions in the mitigation of, and adaptation to, climate change and range from policy interventions such as REDD + (Reducing Emissions from Deforestation and Forest Degradation), and land-use certification schemes (such as for coffee, tea, and cacao), through cooperatives and credit associations to the construction of biodiversity corridors and integrated pest management. In East Africa, a project aimed at identifying, verifying and scaling up climate-smart farm management practices that both increase productivity and emit fewer greenhouse gases (GHGs) per unit of produce has so far found two candidates (Rosenstock et al., 2015). One is the use of leguminous trees to intensify cereal production in Tanzania, and the second is an integrated crop-livestock system combining agroforestry and pasture for smallholder dairy production in Kenya.

Regarding the identification of socially just strategies for enhanced adaptation to climate change, it is necessary to understand the numerous and diverse barriers to adaptation which relate to biophysical, knowledge, and financial constraints on agricultural production and rural development (Shackleton et al., 2015), as well as those political, social, and psychological barriers which are often hidden. The financing of integrated landscape management poses a challenge as national and international planning processes tend to operate sectorially with crops, livestock, fish, forests, wildlife, the environment and rural development individually managed. Consequently, financial strategies for integrated landscape approaches are under discussion (Shames et al., 2014).

To conclude this section, an integrated landscape approach recognizes the importance of the continua of multifunctionality, transdisciplinarity, participation, complexity, and sustainability that exist across a landscape (Freeman et al., 2015). The application of this approach to enhancing sustainable agriculture is still in its infancy, but the combination of the ability to recognize and interpret landscape functions appears to hold out great promise for the effective delivery of integrated production, conservation and livelihood functions, as well as tackling the complex issues affecting climate change, about which there is some controversy (van Noordwijk, 2014).

Target 11: Maintain Global Functions

Concern about the unsustainable trajectory of agriculture globally has been evident since the Club of Rome report (Meadows et al., 1972) and yet subsequent legally binding instruments such as the Rio Conventions have barely affected the trajectory of development. Consequently, the Intergovernmental Panel on Climate Change still recognizes agriculture as a major challenge to the tackling of climate change (IPCC, 2007). Thus, any discussion of sustainable intensification of agriculture that omits the need to address mitigation and adaptation targets is clearly out of touch with reality. There are two challenges in this regard: the first is to adapt, promote and adopt agricultural practices that have been shown to mitigate climate change by improving carbon sequestration in standing biomass and to enhance adaptation through increased soil organic matter, so conferring climate-smart resilient agroecosystems (Harvey et al., 2014), such as diverse mature agroecosystems.

The second challenge is to provide metrics that allow an assessment of progress toward sustainability goals and promote adaptive learning and improvement of governance and management systems. This is even more difficult. Gross domestic product (GDP) is the most widely used metric of development since Kuznets first proposed its precursor gross national product, but it is not highly appropriate in the sustainability context as acknowledged by its inventor who said "the welfare of a nation can scarcely be inferred from a measure of national income" (Kuznets, 1934). A number of alternative metrics have subsequently been proposed (Pretty, 2013; Kubiszewski et al., 2013), but so far none has received the global acceptance required to allow it to be used to assess the sustainability of ecological, economic, and social functions necessary to assure the well-being of the growing number of people on the planet (Bernard et al., 2014). This may change shortly with the adoption of new accounting approaches by the international community that aim to account for ecosystem services as well as their economic performance (European Commission, OECD, UN, World Bank, 2013).

HAVING IDENTIFIED ACTION-ORIENTED TARGETS FOR SUSTAINABLE INTENSIFICATION, WHERE DO WE GO FROM HERE?

Based on the 11 targets for transformative action presented here, along with their associated information, we suggest that sustainable intensification involves the processes that reverse the downward spiral of the cycle of land degradation and social deprivation (Fig. 39.1). Through a combination of applied agroecology and income generation, there are realistic opportunities to rehabilitate hundreds of millions of hectares of degraded/abandoned farmland, while also raising productivity and alleviating the associated complex of social and economic constraints that lead to continuing hunger, malnutrition, and poverty. Building on these outcomes, there are also opportunities for further economic growth. 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. This expansion of the local economy and the ability to purchase imported food does not seem to have been taken into account when predicting the required scale of future agricultural production (Foley et al., 2011). 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 sustainable intensification could have very important impacts on global agricultural production and create new and more sustainable horizons for local economic and social growth, as well as for global agriculture.

The approach presented integrates numerous different concepts of more sustainable agriculture (agroforestry, climate-smart agriculture, conservation agriculture, ecoagriculture, integrated landscape management, integrated rural development, and organic agriculture) with some conventional Green Revolution technologies (improved varieties, chemical fertilizers, pesticides, etc.). In particular it uses the domestication of hugely underutilized resources of traditionally important food and nonfood indigenous tree species as the means to intensify these concepts of sustainable agriculture, by creating a new suite of locally important socially-modified cash crops, with potential for creating new businesses and industries (Leakey, 2012b). Furthermore, trees deliver unique environmental benefits in terms of the protection of soils and watersheds, carbon sequestration, and development of fully functional agroecosystems (Leakey, 2014e; Atangana et al., 2015). Thus, in contrast to the concept of trade-offs between production and good environmental management, there is a synergism that goes a long way toward a fuller and more inclusive concept of sustainable intensification, which better addresses the needs of smallholder agriculture in the tropics and subtropics, especially in Africa.

In conclusion, the combination of restored agroecological function and income generation provides a way out of hunger, poverty and environmental degradation, by closing the yield gap and meeting the needs of poor, smallholder farmers. In these ways it meets the key requirements for sustainable intensification identified by Pretty et al. (2011) and Pretty and Bharucha, 2014), by simultaneously addressing its three components (ecological intensification, genetic intensification, and market intensification) (Conway, 2012). The issue, of course, is whether or not there is the political will to develop and implement appropriate policies for its application.