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Socially Modified Organisms in Multifunctional Agriculture - Addressing the Needs of Smallholder Farmers in Africa

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Abstract

To address on-going issues of hunger, malnutrition, poverty and land degradation in Africa, smallholder farmers are developing Socially Modified Crops as part of a 3-step approach to a multifunctional farming system that impact positively on the social, economic and environmental constraints to farm productivity responsible for the gap between potential and actual yield. Furthermore, these new crops also rehabilitate, diversify and intensify the agroecosystem, diversify local diets and generate income from trade and new value-adding business opportunities.

Keywords

Agroecology, Domestication, Food security, Marketing and trade, Nutritional security, Poverty alleviation, Rural development

Introduction

Issues of hunger, malnutrition and poverty still prevail affecting around a billion people [1] despite the substantially increased potential yields of major crops achieved by the Green Revolution [2]. The successes of the Green Revolution have been achieved by a combination of crop breeding and the use of inputs such as fertilizers, pesticides, irrigation and mechanization, typically cultivated in monocultures on land cleared of other vegetation. However, large-scale, capital-intensive agriculture of this sort is very much better suited to industrialized countries in temperate latitudes than to tropical and sub-tropical countries where farmers have very small farms and live on the very brink of the cash economy. Despite these differences, much attention has been placed on introducing this industrial approach to agriculture across the Developing Countries of the world without adequately recognizing that the smallholder farmers' lack of income is a severe constraint to accessing the essential technical package: improved seeds, fertilizers, pesticides and mechanization. The consequence, especially in Africa, has been severe land degradation and soil nutrient loss, low crop yields and the currently continuing problems of food insecurity [3] - all of which are inter-related with the social and economic issues [4]. Nevertheless, food production globally has been greatly increased and the incidence and impacts of severe famine have been reduced. However, the on-going challenge of matching agricultural production to the needs of a growing population was recognized by Norman Borlaug, the 'father of the Green Revolution'. When accepting his Nobel Peace Prize in 1970, he indicated that the Green Revolution would only be a temporary solution, "a breathing space", in man's war against hunger and deprivation.

The Challenge

Appreciating the above issues, the challenge now is to make further progress in those parts of the world where agriculture is underperforming due to soil nutrient deficiencies and where actual farm yields are well below the potential yields of modern varieties. For example, average maize yield across Africa is about 1.5 tonnes ha^{-1}, while potential yield is around 7 tonnes ha^{-1} [5]. The reasons for this poor performance are very complex, but can be condensed down to a web of interacting social, economic and environmental constraints, such as: deforestation

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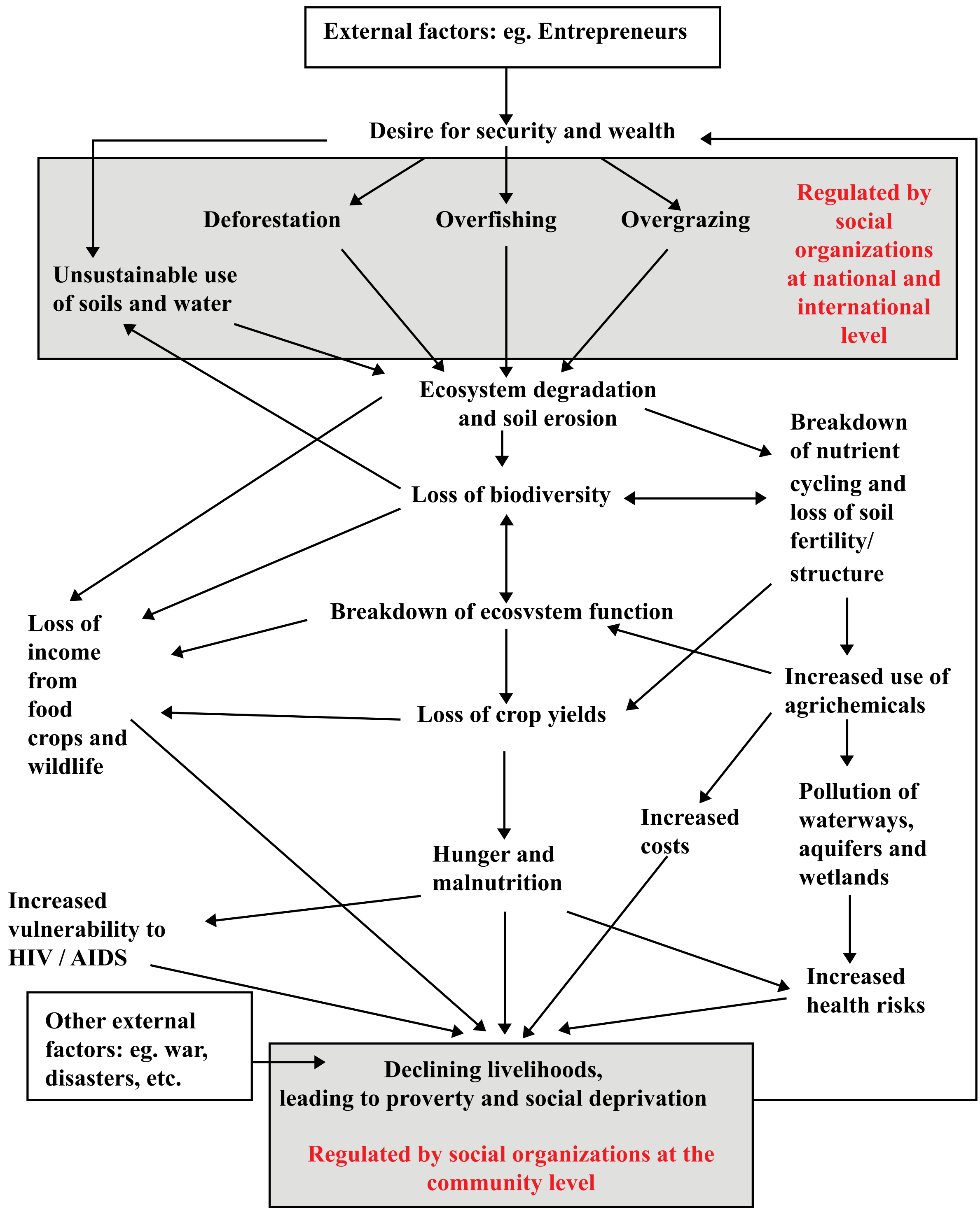

Figure1: Diagram representing the 'Cycle of Land Degradation and Social Deprivation' [6].

and land degradation (loss of soil fertility; breakdown of agro-ecological function, and erosion), poverty, poor education and infrastructure, social exclusion, etc. [6], causing a lack of access to farm inputs. The downward spiral driving this process has been called the 'Cycle of Land Degradation and Social Deprivation' (Figure 1) [4]. Reversing this cycle will require a holistic, multi-functional approach to agricultural intensification that simultaneously addresses the social, economic and environmental drivers of land degradation which are responsible for the loss of crop yield. Thus, it accords with the concept of Multifunctional Agriculture proposed by IAASTD [7] that recognizes the 'inescapable interconnectedness of agriculture's different roles and functions' in rural development (Figure 2).

Interestingly the social issues behind productive tropical agriculture mirror those behind the international de-

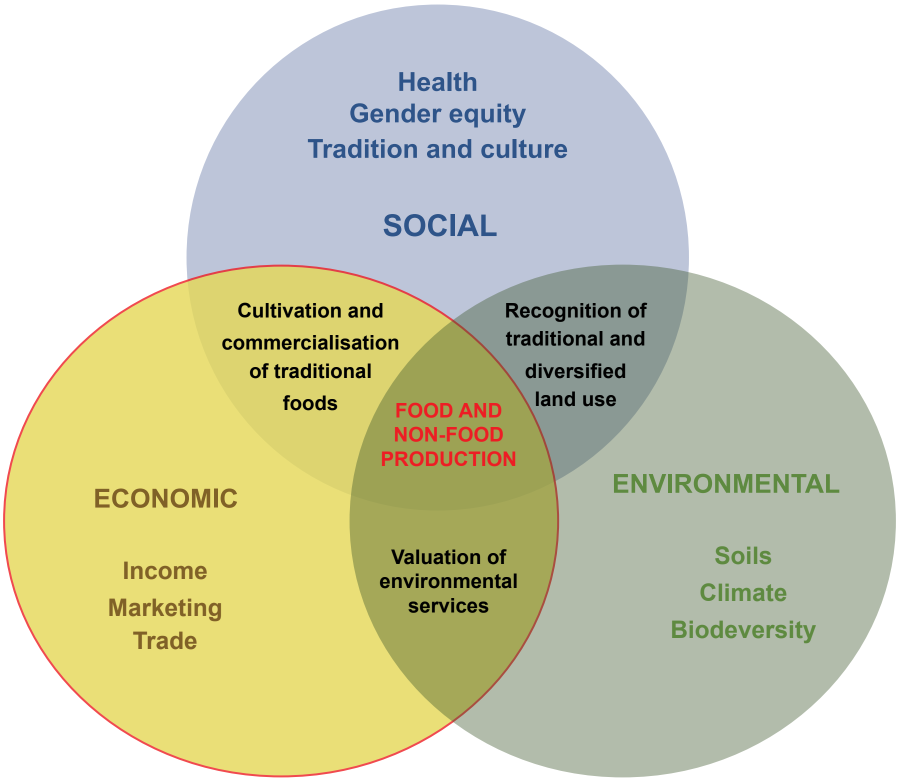

Figure 2: Multifunctional Agriculture - the inescapable interconnectedness of agriculture's different roles [7].

bate on wildlife conservation. The latter has largely focused on two approaches: (i) High input intensification, or 'land saving' and (ii) Less intensive more diversified farming systems, or 'land sharing'. Very appropriately, Bennett [8] has recently suggested that this dichotomy overlooks the need to address both biodiversity conservation within wild-life friendly farming systems, as well as the need to address the needs of poor farmers. This suggestion in fact also conforms to the recommendations of the International Assessment of Agricultural Science and Technology for Development which proposed the concept of Multifunctional Agriculture [7]. Many other international reports have also called for more sustainable approaches to food production, for example: *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture* [9], the *Ecosystems and Human Well-Being* [10] and "*Shaping the Future of Global Food Systems*" [1].

A Solution

Finding practical ways to develop Multifunctional Agriculture should be based on a sound understanding of the downward spiral of the 'Cycle of Land Degradation and Social Deprivation' [6] and good progress has been made by the CGIAR World Agroforestry Centre and its research partners (Table 1). This research combines the ideals of both land saving and land sharing in an integrated 3-step generic model [4,6] to close the Yield Gap and reverse the Cycle of Land Degradation and Social Deprivation [11].

A Generic Model

The three steps of this highly adaptable model, is best illustrated by a Case Study from the South and South-West Provinces of Cameroon involving many farmers, CBOs and NGOs. It was led by the World Agroforestry Centre [12-19] and started with a few farmers in two villages. From these modest beginnings, it rapidly grew over 12 years by local level dissemination of appropriate technology to over 10,000 farmers in more than 500 villages. This rapid adoption is attributable to its close affinity with the needs and desires of local people, and the projects support to village-level capacity building [20]. The key components of this training are: (i) The restoration of soil fertility and agroecological health; (ii) The creation of Socially Modified Crops by the participatory domestication of wild indigenous trees producing useful and marketable food and non-food products at the community level; and (iii) The marketing and value addition of the tree products for local and regional trade [6,11].

Step 1

The first of these steps harnesses the capacity of many leguminous trees and shrubs to fix nitrogen in the soil

Table 1: Research topics involved in the development of Socially Modified Crops for integration into multifunctional agriculture [85].

Topics	References
Strategy for participatory involvement of communities	Franzel, et al. [50], Leakey, et al. [51], Tchoundjeu, et al. [13,14,52]
Techniques and domestication strategy	Leakey and Akinnifesi [53], Leakey [11]
Farmer livelihood strategies	Degrande, et al. [16], Leakey, et al. [54,55], Schreckenberg, et al. [56]
Community capacity building	Degrande, et al. [17], Takoutsing, et al. [57], Franzel, et al. [20]
Characterization of intraspecific variation	Atangana, et al. [36,37], Waruhiu, et al. [38], Anegbeh, et al. [39,40]
Genetic molecular characterization	Lowe, et al. [58], Jamnadass, et al. [59]
Nutrition and sensory evaluation	Leakey, et al. [60,61], Kengni, et al. [62]
Genetic resource management	Tchoundjeu, et al. [12], Kengue, et al. [63], Dawson, et al. [64]
Multifunctional agriculture	Asaah, et al. [15], Leakey, et al. [6,29]
Horticultural protocols	Leakey, et al. [34,35]
Root systems	Asaah, et al. [65,66]
Community constraints and benefits	Schreckenberg, et al. [67], Degrande, et al. [17]
Product processing and value chains	Mbosso, et al. [68], Degrande, et al. [18]
Farmers rights	Gyau, et al. [69]
Uses and markets	Ayuk, et al. [70,71], Cosyns, et al. [72,73], Facheux, et al. [74,75]
Policy	Leakey and Tomich [76], Simons and Leakey [77]
National forest laws	Foundjem-Tita, et al. [78]
Impact	Degrande, et al. [17], Asaah, et al. [15], Leakey, et al. [19,29] Facheux, et al. [79]
Trade, marketing and industry development	Jamnadass, et al. [80,81], Foundjem-Tita, et al. [82,83], Leakey, et al. [31], Gyau, et al. [84]

Table 2: Some examples from Msekera, Zambia of changes in soil physical properties (0-20 cm) due to fertilizer trees/shrubs (Fert Tree) in improved fallows and the control (sole maize) and the % change [24,85].

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 runoff (mins)	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

through a symbiotic association with *Rhizobium* bacteria. Typically, these trees and shrubs can fix 300-650 kg N ha^{-1} yr^{-1} when grown at high density [21], which is considerably more than many commonly cultivated leguminous food and fodder crops which produce 23-176 kg N ha^{-1} yr^{-1} [22]. Trees also produce greater biomass than vegetable crops. In addition, there are soil health benefits from these 'fertilizer' trees and shrubs; such as increased aggregate stability, porosity, and hydraulic conductivity resulting from increased the soil organic matter and improved soil structure and water infiltration (Table 2). Together these benefits improve water use efficiency and rain use efficiency [23]. Furthermore, the trees are a useful source of poles, fuel wood and animal/bee fodder, and provide some control of parasitic weeds, such as *Striga* spp. [24]. The roots of trees also penetrate deeper into the soil profile and so both draw deep nutrients up from below the crop root zone, and provide a web of roots to capture nutrients being leached from the surface soil layers [25].

This low cost and simple 'improved fallow' technology has been widely tested throughout Africa [25,26] and found to typically increase cereal crop yields about 3-fold in 2-3 years. Unlike conventional industrial agriculture, this 'fertilizer tree' intervention is typically implemented on a small scale within a land use mosaic involving mixed cropping on a patch-by-patch basis, usually starting with the areas with severely failing crops. As they be-come productive after a few years their enhanced yield allows the intervention to move on to better land without a reduction in overall food production. If a farmer cannot afford to take any land out of production in this way, the system of Relay Cropping is very effective. The latter involves simultaneously sowing leguminous shrubs with crops such that the shrubs grow as a dry season fallow after the crop has been harvested [27]. As with the application of inorganic fertilizers, the maintenance of soil nitrogen fertility by biological nitrogen fixation is not a one-time solution. However, once the farming system has been diversified with tree crops creating a healthier agroecosystem, the trees do contribute to more permanent nutrient recycling.

Through the biological replenishment of soil nitrogen, crop yields are typically increased to about half the yield potential of modern cereal varieties. This represents a substantial increase in food security for farming households [28]. If sufficiently scaled-up, this 200%-400% increases in actual yield could alone resolve the food crisis in Africa. Sadly, however, there is little sign yet that this potential will be taken up by policy makers. Nevertheless, if adopted to achieve these levels of production, land currently devoted to staple food crops would be freed up on other parts of the farm for cash cropping [6]. To go further and close the Yield Gap (so reaching the full yield potential from the staple food crops) will require other major and minor nutrients from complete fertilizers. Due to their poverty, poor smallholder farmers do not have access to these inputs. Thus, to purchase them an income source is needed [4]. This requirement in addressed by Steps 2 and 3 [29].

Step 2

The second step, which can be implemented in parallel or independently of Step 1, implements the output of more than two decades of research [30,31], aimed at the domestication of useful tropical trees to rebuild important natural forest resources, create new highly nutritious tropical crops for smallholder farmers, and so to generate income in local markets and diversify the local economy. These trees can be integrated into the farming systems in many different configurations and densities. Typically, they are planted at only 10-50 trees per hectare as scattered trees in field systems; in boundary plantings; along the contours to reduce runoff and erosion; as shade for commodity crops like cocoa, coffee and tea; in corners of marginal land, or in home gardens. The benefits in income soon outweigh any loss of production by field crops. This diversification adds resilience to the farming system and to the home economy by reducing the risks from the over-reliance on individual staple food crops. Crucially this diversification also rebuilds the lost functions of degraded agroecosystem, making smallholder farming systems more sustainable, and productive. Ecologically, the planted trees (the planned biodiversity) create niches for colonization by a wide range of wildlife (the unplanned biodiversity) which enrich the food chains, enhance lifecycles and promote the recycling of nutrients, etc., with important beneficial impacts on pests and diseases [32]. In Africa, this mosaic of diversification typically contains both exotic and indigenous tree species in approximately equal numbers and is well suited to smallholder farms across the tropics and sub-tropics [6]. From a regional, global and landscape viewpoint, these biodiverse farming systems, which are unlike the monocultures found in industrial agriculture, help to conserve wildlife [32].

The above concept of domesticating indigenous trees has been undertaken in response to a request from farmers in Cameroon for help to cultivate the indigenous tree

Table 3: List of some African tree species being domesticated for their Agroforestry tree products.

Species name	Common name	Product	Use
Irvingia gabonensis	Bush mango	Kernel	Food thickening
Dacryodes edulis	Safou	Fruit	Food and oil
Ricinodendron heudelotii	Njangsang	Kernel	Spice
Chrysophyllum albidum	Star apple	Fruit	Food
Garcinia kola	Bitter kola	Kernel	Stimulant
Cola spp.	Cola	Kernel	Stimulant
Gnetum africana	Eru	Leaf	Food
Prunus africana	Pygeum	Bark	Medicine
Allanblackia spp.	Nsangomo	Kernel	Oil
Adansonia digitata	Baobab	Leaf and fruit	Food
Vitellaria paradoxa	Shea nut	Kernel	Food
Parkia biglobosa	Néré	Kernel	Food
Tamarindus indica	Tamarind	Fruit	Food
Zizyphus mauritiana	Ber	Fruit	Food
Vangueria infausta	Wild medlar	Fruit	Food
Azanza garckeana	Snot apple	Fruit	Food

species that have provided a wide range of traditionally important, and marketable food and non-food products [6]. These products are now called Agroforestry Tree Products (AFTPs) to distinguish them from the common-property resources known as Non-timber Forest Products or NTFPs gathered from natural forests and woodlands [33]. The species producing these products have been overlooked by mainstream agriculture [30]. To implement this domestication programme, an international team has worked to empower local village communities to cultivate and improve a wide range of local food species (Table 3). This process has involved the use of robust, but simple, horticultural techniques of clonal propagation (rooting stem cuttings, marcotting and grafting [34,35]) to capture the desirable traits of elite individuals within the existing wild resource of the species. In contrast to tree breeding, this horticultural approach allows farmers to rapidly create their own high quality cultivars from sexually mature shoots [14,29], which allows these cultivars to start fruiting in only two to three years. These domestication techniques are equally applicable to exotic species like mango, avocado, cocoa, etc.

The process of tree domestication developed in Cameroon is a 'grassroots', self-help, participatory approach, involving community capacity building in simple and locally-appropriate techniques to capture the elite individuals from among individual village tree populations. For example, the creation of clonal cultivars can be done in a village nursery without the need for electricity or piped water [34,35]. Likewise, simple genetic characterization studies have been done in many of the 50+ tropical and sub-tropical species being studied [6] to acquire an understanding of the extent and complexity of genetic variation in populations of these wild species. This research has been focused on the selection of elite trees at the level of village population. Typically, it has been found that there is 3- to 10-fold tree-to-tree intraspecific variation in these small populations [36-41]. This indicates that there are great opportunities to develop elite cultivars with a wide range of different traits, and that they can be combined to form an 'ideotype' to meet the needs of different uses, marketplaces and even new industries [42]. Some of these studies have used molecular techniques and they have found that these village populations contain about 80% of the intraspecific variation [43] making a decentralised approach to domestication by social modification both effective and low risk [6,19]. Gepts [44] has described this decentralized approach to the domestication of new tree crops as particularly appropriate because it addresses the needs of local farmers, as dictated by local adaptation and consumer preferences. Importantly, the farmers control the process and are the beneficiaries of their innovations and work [6,11,17]. This is, therefore, an empowering process that is transforming the lives of the participating communities. The highly participatory nature of our approach to tree domestication, together with its aim to address the local social and economic constraints limiting the success of local agriculture, characterizes the concept of these cultivars as Socially Modified Organisms [45,46] - new crops created by individual farming households through the domestication of elite individuals from within existing wild genetic resources.

This innovative participatory approach to developing new crops does, however, come with the risk of biopiracy. So, there is a need to develop ways to ensure that the farmer's intellectual property is not misappropriated by unscrupulous entrepreneurs [47]. New approaches to registering the intellectual property of smallholder farmers within global frameworks have been suggested [48], but work is still needed to implement them.

Step 3

The third step to creating multifunctional agriculture involves the post-harvest processing, value-adding and marketing of the Agroforestry Tree Products from these Socially Modified Crops. To maximize the benefits from commercialization, this step should follow behind the domestication process, as the regional and international end of the value-chain demands a reliable supply of top quality and uniform products [49]. It is important to recognize here that traditionally, many of these locally-important indigenous food species are currently well recognized and appreciated in local markets as wild resources, and that they are already a valuable source of cash to supplement the income of people living on only a few dollars per day. Some international commentators have described these products a 'famine foods', but for many of these species this is a misnomer [33], as they are greatly appreciated and recognized in local culture. They are frequently and widely traded by women in local markets providing important household income. Many women are keen to expand and develop this trade, and are developing new businesses [47]. Some of these involve local processing and value addition (eg. Manyu Women's Multipurpose Cooperative in Cameroon [MAWACOOP]). Building on the work to characterize the genetic diversity in wild fruit and nut species, 'ideotypes' are being used to direct the domestication process towards the selection of cultivars with highly desirable, but perhaps uncommon, combinations of genetic traits [42]. Thus, the traditional market potential can be transformed to create opportunities for new business and employment in new local industries [49]. Furthermore, the domestication process improves the uniformity of the products being marketed and should also improve the reliability of quality and supply in the expanding value-chains.

At the community level, income from village nurseries has risen from almost zero to an average of $28,350 in ten years [29]. The product commercialization step further expands the financial benefits in the rural economy. For example, one group of 10 women each made profits from processing food crops of around US $3000-$4000 per year; while a group of local metal workers making equipment for drying, and grinding products generated income over US $120,000 [29]. By creating employment in this way, this initiative has also created employment outside of subsistence farming and has brought local people into the cash economy. These and other impacts [19,29] all have important implications for social equity and justice [11]. The extra income generated by farming households also allows them to improve local infrastructure; to purchase farm inputs such as fertilizers and livestock, and so to initiate a series of improvements that further improve household well-being [19,29].

Conclusion

This African initiative by farmers and researchers in Cameroon has focused on innovative and practical ways to restore productivity in Africa to levels not attainable by conventional crop breeding and genetic modification of staple food crops. It thus offers a new and more appropriate paradigm for the intensification African agriculture - one that also combats land degradation, hunger, malnutrition and social injustice. This approach which encompasses a focus on under-utilized, indigenous food species is also applicable to exotic species and is equally relevant in Latin America, South and South-East Asia, and in Oceania. Specifically, it includes the development of socially-modified new crops as part of a 3-step approach to multifunctional farming systems by subsistence farmers and addresses the social, economic and environmental constraints to farm productivity. Overcoming the constraints which have created the gap between potential and actual yield has so far alluded those trying to improve the food security of many millions of tropical and sub-tropical farmers. Sadly, this problem has been inadequately recognized by international policy makers, but perhaps with new insight this can now be addressed. Importantly, this approach also diversifies the agroecosystem and the rural economy in novel ways. The package of new opportunities includes the diversification of local diets and the generation of income from trade and new value-adding businesses. This more sustainable approach to tropical agriculture has been tried and tested on a small-scale. It now needs to be scaled-up to have real impact, to improve the lives of the world's most vulnerable people, while also contributing to the resolution of some of the big social issues behind climate change, illegal immigration and social conflict.

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