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Knowledge gaps and research needs concerning agroforestry's contribution to Sustainable Development Goals in Africa

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This review addresses the role of agroforestry in the links between food security and agricultural sustainability in Africa. We illustrate that the products and services flowing from the integration of trees within farming systems can contribute to food security, farmer livelihoods and environmental resilience. However, for agroforestry to be adopted it should not be constrained by policies which hinder the integration of trees, with crops and livestock. This policy scenario can best be met when the governance of food production at local to global scales is multi-sectoral and based on a 'Systems Approach'. Nevertheless, the adoption of agroforestry has recently been greatly supported by the international agenda on the mitigation of climate change and to achieve sustainable food production. In conclusion we pose the hypothesis that ''Agroforestry concepts and practices can form an effective, efficient and fair pathway towards the achievement of many Sustainable Development Goals'', and discuss the main messages and research questions emerging from the papers presented in this special issue.

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Harnessing sustainable food production from agroforestry

Improving and sustaining agricultural production in Africa under conditions of increasing climate variability will require increased attention to environmental sustainability, especially the crucial neglected roles that trees can play. Agroforestry science can be seen as the body of knowledge and set of practices that explore and guide the integration of trees into crop, livestock and mixed agricultural systems at nested scales from a farmer's field to large agricultural landscapes. As such it can play an important role in determining where trees can contribute to improving food and nutrition security, livelihoods and the delivery of ecosystem services [1••,2]. Improvement to the social and biophysical environment and other ecosystem services are among the multiple benefits that can be delivered simultaneously by agroforestry [3], creating a system where the whole is more than the sum of its individual components [4••].

Successful agroforestry systems require enabling conditions such as governance, gender synergies, secured land tenure, investment, markets for agroforestry inputs and outputs [5,6•]. It might be challenging to meet all these requirements but most instances of success are reported when local communities are the initiators of transformative change of land use management [7] and where there are favourable biophysical conditions, appropriate tree and crop germplasm, adoption of adequate management practices and integration of agroforestry within rural livelihood systems [8].

Against these backgrounds, agroforestry must be viewed as a land use system that seeks to deliver sustainable improvements to food security, through integrating trees with other components of agriculture in multifunctional landscapes. This can include, for instance, knowledge on the protective roles of permanent vegetation on slopes and fragile soils or reduction of risks due to climate change [4,9]. It requires, however, a fundamental break with institutional traditions that have segregated agriculture, forestry, rural development, agrarian issues of land reform and environment as separate domains of policy development and implementation. Successful land management should embrace the need to manage all aspects of the systems, not only productive aspects. In Africa there is a need to demonstrate that relevant aspects of emerging sustainability needs are appropriately addressed in relation to rapid acceleration of environmental change in these landscapes.

This paper is a synthesis of a special issue showing the way agroforestry seeks the entry point of how and under what conditions manipulating the tree component in farming landscapes, at various nested scales, can add value to sustainability goals. It is not surprising that there is a growing recognition that trees are key elements to the achievement of Sustainable Development Goals (SDGs) as they support many environmental 'must

haves' such as climate stability, reduction of biodiversity loss, safeguarding ecosystem services, and regulation of biogeochemical cycles including water [10]. There are nevertheless many outstanding challenges that remain in order for agroforestry to contribute more effectively to SDGs.

Service and commodities: challenges and requirements of successful agroforestry systems

Trees contribute to food security in Africa through a range of environmental benefits, provision of products and social co-benefits such as increased farm income [11–13], restoration and maintenance of above-ground and below-ground biomass and biodiversity [4,14,15], restoration of biological corridors between protected forests [13,16], maintenance of watershed hydrology [9,17], improved soil conservation [4,9,18], availability of timber and fuel wood [19,20], and ultimately reduction of pressure on natural forests.

The actual debate on designing the right agroforestry system is very intense, that is, selecting the right tree and the right management option to achieve climate smart objectives that have the desired social and environmental benefits [21]. Much evidence of successful agroforestry systems has been documented in different African biomes [22–26,27•,28,29••], but this is mostly based on specific resources or typical management systems. Developing and monitoring relevant indicators of successful agroforestry systems is necessary to test the practicality of relevant key scientific hypotheses (e.g. *agroforestry is the future of land use* [30••]) and build on experience of good practice to inform the extent to which desired sustainable development outcomes can be achieved through agroforestry (Table 1).

On the evidence of this special issue, it is clear that successful agroforestry systems require favourable sites [18], appropriate tree and crop germplasm [31], adoption of suitable management practices and integration of those practices into rural livelihood systems [4,20,32–35]. Agroforestry as a support for sustainable livelihoods in Africa requires that species must be carefully selected to respond to local priorities and biophysical conditions in order to optimize production benefits and environmental services. A starting point for valuing agroforestry products stems from the development of quality seeds and genetic resources as a means for improving food and nutritional security in sub-Saharan Africa [12]. Tree seeds and seedlings must be produced in sufficient quantities and effectively and efficiently disseminated to farmers. Unfortunately, adequate supply chains of high-quality planting materials are the exception rather than the rule and often do not then extend to African smallholders interested in introducing trees into their farming systems. Yet without effective provisioning systems, adequate policy agenda that secure land tenure and markets, planting the right tree at the right time and in the right place remains impossible for many farmers [11,36,37].

Additionally, many journal articles underline the requirement to be more explicit in the inclusion of agroforestry in global initiatives on climate change adaptation and mitigation [6,23,38,39,40•,41–43]. The contribution of agroforestry to mitigation strategies, under conditions where adaptation is the highest priority for farmers, needs to be scrutinized to avoid clashes between development goals and exclusively climate oriented perspectives [44]. Since trees are long-lived organisms, likely climate change impacts should be taken into account whenever species recommendations are made. Yet selecting the right species is not sufficient, future growing conditions are likely to affect the resilience of agroforestry systems [45,46•].

Finally, for tree planting to be successful, trees require appropriate care. Unmanaged trees will often not be productive, and they may compete with other elements of the farming system. To realise the potential of agroforestry, more insights are needed on management regimes that work best under given conditions.

Gaps and conditions for successful agroforestry that work for the poor

No single approach to food security will be sufficient because of policy failures in controlling demand and supply dynamics of the food system [47•,48]. To assure food security over the long term requires integrating complex land use systems that improve agriculture and the delivery of ecosystem services. This will require development practices that integrate and build on the diversity of species and production systems, the value chains and knowledge systems that are essential for sustainable agriculture [49••]. Diversity and complexity should be pursued through integrated landscape management that have small-holder farmers as their main focus [50•]. Hence, sustainable intensification of agriculture that builds on diversity, indeed seeks to realize a 'diversity dividend', is seen as a necessary pathway to address the dual objective for food security and avoidance of adverse impacts of climate change [31,49].

Many gaps exist when using agroforestry in rural areas in Africa. Agroforestry is one model of an integrated land use approach that can favour increased production using low input technology [6,43,51] but requires advance policy actions (right institutions, local capacities, adapted technologies, social context, equity, gender, governance) [52]. Policy should also manage the demand side in relation to population growth and change in diet [37,49,53], particularly with growing urban populations.

Table 1

Tentative set of Sustainable Development Goals and associate targets as discussed around June 2013 in relation to potential contributions of agroforestry and issues that require further discussion

Goal	Target	Potential AF-related contributions	Issues for further discussion	References
1. End poverty	1a. Bring the number of people living on less than $1.25 a day to zero and reduce by *X*% the share of people below their country's 2015 national poverty line	Improve market and market value of agroforestry products; Improved genetic resources and tree planting in AF	Developing efficient commodity chain with a multi-actor approach; Scaling up good domestication practices	[11] [12]
	1b. Increase by *X*% the share of women and men, communities and businessmen with secure rights to land, property and other assets	In most agroforestry system women are responsible of managing trees target women's enterprises through AF	Need to address the social and resourcing barriers constraining women's groups Improving micro-credit at local level	[52]
	1c. Cover *X*% of people who are poor and vulnerable with social protection systems	Rural enterprises based on agroforestry products	Appropriate and adequate financing for AF enterprises of all scales	
	1d. Build resilience and reduce deaths from natural disasters by *X*%	AF can buffer Climate change impacts by building resilient ecosystems and can contribute to carbon sequestration	Evaluation of the role of trees in buffering climate impacts	[4,13,21,34]
2. Empower girls and women, and achieve gender equality	. . . 2d Eliminate discrimination against women to own and inherit property. . .	Women can develop rural enterprises on agroforestry products and increase their share of cash returns from agroforestry products	Land ownership is still an issue in most agroforestry systems where land belong mostly to men	[12,52]
3. Provide quality education and lifelong learning	. . . 3d. Increase the number of young and adult women and men with the skills, including technical and vocational, needed for work by *X*%	AF requires use of knowledge on land management. Knowledge sharing is provided to all social groups including vulnerable communities	Translation of technical knowledge into local language Knowledge management including local knowledge	
4. Ensure healthy lives	4a. End preventable infant and under-5 deaths	Nutritional value of agroforestry products particularly indigenous trees	Improve knowledge on nutritional values of agroforestry products	[12]
5. Ensure food security and good nutrition	. . . 5a. End hunger and protect the right of everyone to have access to sufficient, safe, affordable and nutritious food	Low cost and high quality food and fodder from indigenous trees	Balancing food crops with cash crops using sustainable land use management	[60]
	5b. Reduce stunting by *X*%, wasting by *Y*%, and anaemia by *Z*% for all children under five	High nutritional values from some AF species (vitamins, carbohydrates and other food groups)	Policy engagement to promote locally valued fruit trees	[12,60]
	5c. Increase agricultural productivity by *X*%, with a focus on sustainably increasing smallholder yields and access to irrigation	Agroforestry can improve soil fertility, buffer climate impacts and contribute to sustainable increase in yield	Importance of agroforestry beyond carbon, especially for water	[3,9,12,31, 61–63]
	5d. Adopt sustainable agricultural, . . . practices	Climate smart agriculture through AF	Balancing the need to address urgent food demand with requirements for adoption of sustainable development pathways	[6,43,51]
	5e. Reduce postharvest loss and food waste by *X*%			

Table 1 (*Continued*)

Goal	Target	Potential AF-related contributions	Issues for further discussion	References
6. Achieve universal access to water and sanitation	...			
	6c. Bring freshwater withdrawals in line with supply and increase water efficiency in agriculture by *X*%...	Conservation agriculture with trees, ecological corridors that buffer climate extremes including high temperatures	Quantitative understanding of the contribution of evapotranspiration from trees outside forest to regional to local, global rainfall patterns	[4,9,13,17,19,31]
	6d. Recycle or treat all municipal and industrial wastewater prior to discharge	Non-food trees are relevant for low-cost waste-water re-use	Buffering non-point pollution using trees	
7. Secure sustainable energy	7a. Double the share of renewable energy in the global energy mix	AF can increase tree cover globally without compromising food security	Land grabbing for bioenergy	[40•]
	...			
	7c. Double the global rate of improvement in energy efficiency in ... agriculture ...	AF reduces the use of mineral fertilizers	What is the contribution of N fixing trees in GHG emission	[61,64]
	...			
8. Create jobs, sustainable livelihoods and equitable growth	...			
	8b. Decrease the number of young people not in education, employment or training by *X*%	Developing the potential of agroforestry in rural areas will employ more people	New extension models that works for poor communities	
	8c. Strengthen productive capacity by providing universal access to financial services ... and ICT			
	...			
9. Manage natural resource assets sustainably	9a. Publish and use economic, social and environmental accounts in all governments and major companies	Policy relevant information on agroforestry related environmental services	Quantitative evaluation of some ecosystem services	
	9b. Increase consideration of sustainability in *X*% of government procurements	Support sustainable intensification using low input and high recycling rate of AFS	Improving national investment in AFS	
	9c. Safeguard ecosystems, species and genetic diversity	In situ genetic conservation and ensure communities benefits (Aichi Biodiversity goals): http://www.cbd.int/sp/targets/	Knowledge of biodiversity status and threats	
	9d. Reduce deforestation by *X*% and increase reforestation by *Y*%	Increase in tree cover can be achieved by promoting AF	Definition of forest vs. farming lands	[65,66]
	9e. Improve soil quality, reduce soil erosion by *x* tonnes and combat desertification	Protective AFS such as wind-fires breaks, alley planting, conservation agriculture with trees, nitrogen fixing trees	Impact of management practices on soils	[4,31,61]
10. Ensure good governance and effective institutions	...			
	10b. Ensure people enjoy freedom of speech, association, peaceful protest and access to independent media and information	Collective action in agroforestry could be a platform to trigger social participation and organizational dynamics	Internal democracy in local rural organizations and the gender balance	
	10c. Increase public participation in political processes and civic engagement at all levels	Recognition of land as a common benefit that requires community inclusive stewardship	Land privatization with increasing market incentives	
	10d. Guarantee the public's right to information and access to government data	Mainstreaming agroforestry in national policy could support this goal	Translate scientific knowledge to decision makers	
	...			

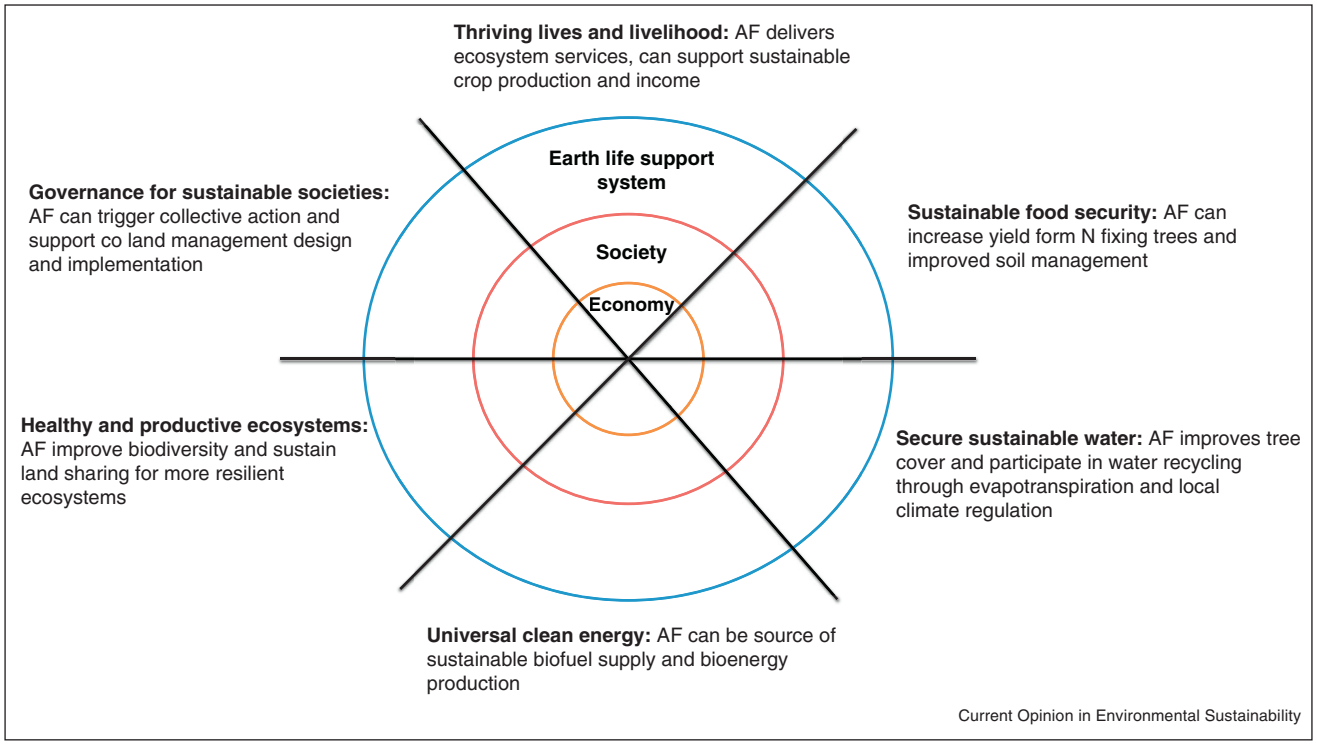
Table 1 (*Continued*)

Goal	Target	Potential AF-related contributions	Issues for further discussion	References
11. Ensure stable and peaceful societies	...			
12. Create a global enabling environment and catalyse long-term finance	...			
	12c. Hold the increase in global average temperature below 2°C above pre-industrial levels, in line with international agreements	AF is seen as a way to mitigate climate change by improving carbon stock and supporting water recycling	How tree will respond to changing temperature and rainfall in Africa	[9,13,14,17, 19–21,34,45,61]
	...			
	12f. Promote collaboration on and access to science, technology, innovation and development data	AF as a basis for integrated research	Cross organizational collaboration (joint research agendas and frameworks)	[7,20,32,36]

On the issue of equity and taking into account vulnerable social groups, there is a need for understanding of whether gender specificity in decision-making affects the multifunctionality of landscapes [33]. According to Villamor *et al.* [33], we need mechanisms or frameworks that engage women in decision making to improve adoption of agroforestry. A better knowledge of value-chain actors and consumers, specially focussing on promoting the involvement of women, and diverse markets for the wide variety of tree products and species is required. In practice, women are as actively involved as men, however, their level of participation is constrained by cultural norms and lack of resources [52].

Additionally, agroforestry cannot be successful if it is inconsistent or disconnected with other land management objectives [37]. Addressing biodiversity and sustainable land use within multifunctional landscapes goes beyond land sharing or integrated resource management; it requires avoiding parallel and not fully integrated

Figure 1



Potential contribution of agroforestry to SDGs (adapted from Griggs *et al.* [1••]). *Note*: AF: agroforestry; SDGs: Sustainable Development Goals.

polocies between the forest sector and the agricultural sector. One important aspect is to align food security and income generation in sustainability (combining foodfeed and cash needs).The requirement of market information systems to not only support products valuation but also deliver comprehensive, analytical information on other aspects of markets, including trade with regional or international markets is a key success parameter for efficient interventions through rural collective action [11]. To optimize the benefits of agroforestry products therefore requires multiactor institutions, polycentric but integrated decision making, sharing of knowledge and experience along with better incentives and advocacy capacities [12].

To help us understand just how agroforestry can address the above gaps and subsequently support sustainable development and eventually contribute to emerging SDGs we pose the hypothesis that ''agroforestry concepts and practices can form an effective, efficient and fair pathway to achievement of an important part of Sustainable Development Goals''. We explore this hypothesis in the following based on the papers in this special issue and the literature on the challenges of delivering services and commodities in agroforestry systems.

Prospects of agroforestry's contribution to SDGs in Africa

The missing links between research and decision making are strong impediment to achieving sustainability goals [54,55•,56], especially in natural resources dependant societies of Africa. Since agroforestry is not normally included in government statistics and many practices are difficult to detect via proxies and other conventional methods, estimates of the extent of agroforestry as well as trends in the use of trees on farms are scarce [57,58]. Yet the little information that is available indicates that use of trees on farms is increasing in many areas [28,29,55•]. Detailed land use and land cover assessments, such as the recent FAO Global Forest Assessment [59], do not normally consider agroforestry as a separate land use category; hence many agroforestry systems are either classified as agriculture or as a kind of forest. Judging the current and potential future contribution of agroforestry to rural livelihoods throughout the developing world will require more efforts into assessing the potential of agroforestry systems to support development needs. The growing interest of AFS for sustainable development is likely to increase [1••] because of the clear connection between the universal SDGs and what agroforestry can afford to achieve them (Figure 1 and Table 1). In Table 1 we map many SDGs against potential contribution from agroforestry and issues for further discussion and research action.

Conclusion

As we begin to recognize that there are no simple solutions to the complex challenges of food security and climate change, we have also recognized in this special issue that pure technological approaches are important but not sufficient to respond to environmental challenges. In this context the importance of developing our knowledge base in ways that explicitly recognize the complexity of assuring food and nutrition security, while improving the livelihoods of a rapidly growing human population, and assuring a continued flow of the ecosystem services that assure life on our planet becomes of paramount importance. In this special issue we have laid out agroforestry as a rapidly growing body of knowledge and sets of practices that explicitly recognize and seek to deal with the complexity of natural, social and economic systems at nested geographic and temporal scales. Agroforestry combines traditional and more recent research based knowledge and evidence related to optimizing the interactions of trees, crops, livestock, water, soil, social systems, economic systems such as markets and value chains in order to respond sustainably to challenges of development and sustainability.

Inherent to the way these diverse strands of knowledge and practice are woven together in working systems that deliver goods and services for communities is an explicit recognition that diversity is a value that is likely to deliver a dividend that has so far eluded competing drives to simplify agriculture in managed landscapes. In this context, agroforestry is rapidly drawing on methods and tools associated with complexity science for development.

There are other aspects of this body of knowledge that are particularly suited to responding to complex challenges, such as climate change, particularly the importance of cataloguing the systems that are resilient, responsive and flexible and based on functional diversification of our farming landscapes. Contrary to many expectations, the resulting systems are not just more resilient than the preceding systems they are most frequently also more productive. As a result of the twin characteristics of building on diversity and building towards productive resilience Agroforestry Systems tend to be efficient users of resources and more effective in the delivery of multiple benefits for people, climate and the environment. They cannot do this under all conditions, so an important facet of the science and knowledge base of agroforestry practices and systems is the determination of the conditions that constrain success of the kind described above.

Papers in the special issue raised major questions regarding ways agroforestry knowledge should be gathered to deliver a comprehensive synthesis that supports emerging sustainability goals. Some of these questions are expressed below.

- What are the multiple benefits of agroforestry in developing countries, including emerging issues such

as value of ecosystem services, carbon and biofuel? [4,9,11,12,31,32].

- How can adoption of agroforestry be increased considering the variety of options, local needs and ecological conditions? How to address the social barriers including equity and gender issues? [12,33,36].
- How can agroforestry recommendations be adjusted to harmonize with emerging climate change goals, such as REDD+ or any type of payments for environmental services including carbon finance and how can agroforestry help farmers adapt to climate change? [4,14,16,17,21,45,61]
- What support is needed to increase the contribution of tree-based cropping systems to smallholder incomes in order to diversify income sources and increase food security? [11,13,20,32]. What are the political challenges of using agroforestry as way to reduce the yield gap in Africa?
- What are the agroforestry land use systems that represent high performing practices [67] and what are the crucial areas where region/country-specific agroforestry systems should be developed using required matrix and indicators of longer-term goals for sustainable development across scales (region to landscape)?
- How to increase the opportunities for countries to identify similar agroforestry land use systems to better share knowledge on improved production practices, environmental sustainability, resilient and resource efficient farming systems? This question includes the identification of critical needs for measuring and monitoring performance of agroforestry systems, [47,68]?
- Why do we still have little integration between agriculture and forestry in the countries' policy and administration when agroforestry is one of the mainstays of local economies and while subsistence farmers happily maintain trees in farming lands?
- How to re-interpret drivers of deforestation to avoid inaccurate and contentious conclusions regarding the contribution of subsistence farming to deforestation, rather than seeing opportunities for improving ecosystem health?

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