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Agroforestry solutions to address food security and climate change challenges in Africa☆

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Trees inside and outside forests contribute to food security in Africa in the face of climate variability and change. They also provide environmental and social benefits as part of farming livelihoods. Varied ecological and socio-economic conditions have given rise to specific forms of agroforestry in different parts of Africa. Policies that institutionally segregate forest from agriculture miss opportunities for synergy at landscape scale. More explicit inclusion of agroforestry and the integration of agriculture and forestry agendas in global initiatives on climate change adaptation and mitigation can increase their effectiveness. We identify research gaps and overarching research questions for the contributions in this special issue that may help shape current opinion in environmental sustainability.

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Introduction

Thirty-five years ago widespread concerns over land degradation and the lack of effective solutions in Africa led to the hope that international agroforestry research could contribute new solutions [1]. Despite local success stories [2••], many parts of Africa have continued to experience food insecurity, declines in per capita farm income, and land and soil degradation, aggravated by biodiversity loss [3,4]. Where climate is highly variable, especially in the drier parts of Africa, many observers have begun attributing recent land degradation to climate change [5]. Indeed, projected future climate change is almost certain to affect negatively the agricultural resource base in many parts of the continent [6••,7•,8,9,10].

Many smallholder farmers in Sub-Saharan Africa practice agroforestry. These systems have prevailed despite persistent attempts to introduce monoculture production of annual crops, which have been much less successful in Africa than elsewhere [11]. Agroforestry has been shown to provide a number of benefits to farmers. For instance, it can enhance soil fertility in many situations and improve farm household resilience through provision of additional products for sale or home consumption [12]. The insight that trees on farms provide livelihood benefits is not new, and diversity-based approaches to agricultural adaptation to climate variability have been adopted by many farmers [13]. In light of recurring food shortages, projected climate change, and rising prices of fossil fuel-based agricultural inputs, agroforestry has recently experienced a surge in interest from the research and development communities, as a cost-effective means to enhance food security, while at the same time contributing to climate change adaptation and mitigation. It has also experienced a recent increase in adoption by farmers in many parts of Africa as demonstrated by Garrity *et al.* [2••].

In spite of these success stories, adoption has not been widespread in many parts of Africa, due to a number of reasons related to the performance of agroforestry practices, the political and socioeconomic environment or simply farmers' disposition towards trees on their farms. An active area of research therefore concerns the preconditions that must be met for successful establishment of agroforestry. For these reasons, major research frontiers in agroforestry science are the identification of appropriate extrapolation domains for locally successful practices, better understanding of barriers to adoption and development of strategies to overcome these barriers.

Major obstacles to the spread of agroforestry strategies are the lack of support for such systems through public policies [14], which often take little notice of tree-based farming systems. Consequently, agroforestry is often absent from recommendations for ensuring food security under climate change [10], even though many practices have been shown to deliver benefits for rural development, buffer against climate variability, help rural populations adapt to climate change and contribute to climate change mitigation [15•,16]. Many studies have shown that agroforestry practices can slow or reverse land degradation, sequester carbon from the atmosphere and secure rural livelihoods through provision of ecological and economic benefits. In addition to increasing soil fertility, trees managed by farmers can also provide ecosystem services and functions in addition to the products and services that motivated farmers to plant or preserve them [17,18]. These services are of particular importance in many low-income countries in Africa, where large proportions of the populations work in an agricultural sector that does not attract much investment from either government or private investors [19].

This paper introduces a special issue of Current Opinion in Environmental Sustainability (COSUST) that seeks to explore the potential of agroforestry for providing benefits for livelihoods, as well as climate change adaptation and mitigation. The objective of this Special Issue is to take stock of the current state of knowledge and to flag important research avenues on agroforestry's potential to contribute to food security and to meet the challenge of climate change.

Agroforestry systems in Africa

Throughout Africa, agroforestry systems come in a wide variety of shapes and forms. Many of these systems have little more in common than the coincidence of woody perennials with agricultural crops and/or livestock. Basic data collection by the FAO does not clearly stress the segregation between forests and agricultural landscapes with trees. This can be seen as an historical anomaly rather than a reflection of incompatibility between annual and perennial plants within a farming system [20].

Trees or shrubs on farms and in landscapes can occur as solitary individuals, in lines, as woodlots or in the seemingly random constellations that characterized the forest that was present before the establishment of agriculture. Depending on the environmental, climatic, economic and socio-cultural niches they occupy, different types of agroforestry systems have arisen in different places. Some prominent examples that illustrate the diversity of agroforestry are the parkland systems of the Sahel, multistory homegardens on Mt. Kilimanjaro in Tanzania, cocoa systems in Côte d'Ivoire and rotational woodlots in Kenya. A number of approaches have been proposed for defining a typology of agroforestry practices and systems [18,21,22], but inclusion of multiple characteristics is necessary for grasping all major distinctive attributes of agroforestry systems (Table 1).

Several agroforestry practices can be relevant for different agro-ecological zones, and many systems with a range of different compositions can fulfill essentially the same functions for livelihoods and landscapes. There is thus no single classification scheme that can be universally applied [18]. What differentiates agroforestry from other land uses is the deliberate inclusion of woody perennials on farms, which usually leads to significant economic and/or ecological interactions between woody and non-woody system components [22]. In most documented cases of successful agroforestry establishment, tree-based systems are more productive, more sustainable and more attuned to people's cultural or material needs than treeless alternatives. Yet agroforestry is not being adopted everywhere, and better insights are needed into the productive and environmental performance of agroforestry systems,

Table 1

Diversity of agroforestry (AF) classification.

Typology of AF	Key elements	Examples AF practices	References
Ecological	Geographical location (AF system adaptability to particular ecologies)	Lowland humid or sub-humid tropics AF	[18,22]
Physiognomy	Parkland Mosaic Multistoried homegarden	*Faidherbia*, Shea butter parks in West Africa Long term fallows	[2••]
Compositional/structural	Simultaneous or sequential combination of trees, crop, animal	Trees in pasture and rangelands (silvopastoral) and agriculture (agrosilvopastoral)	[13]
Practices (systems)	Management systems, livelihood strategies	Hedgerows, long term fallows, alley cropping, improved fallow, multilayer tree cropping, woodlots	[18,22]
Functional	Erosion control, soil fertility	Wind breaks, shelterbelts, erosion control/soil conservation, scattered nitrogen fixing trees, boundary planting	[8,23]
Socioeconomic	Scale of production and level of technology, input and management (Commercial, subsistence AF)	Low input, high input agroforestry	[15,24,25]

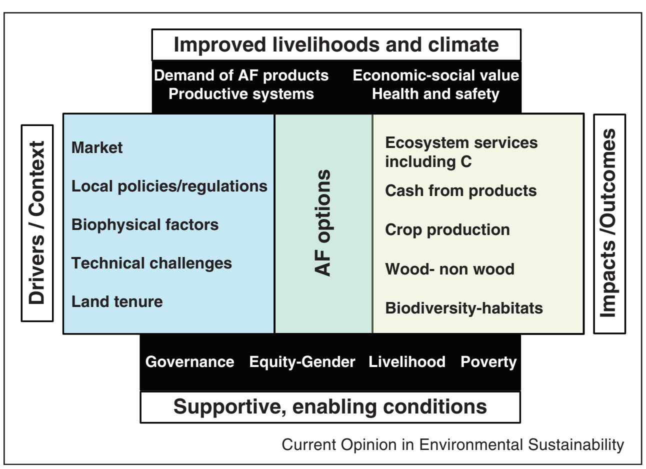
socio-cultural and political prerequisites for their establishment, and the trade-offs farmers face in choosing between land use practices. These site factors are likely to vary at fine spatial and possibly temporal scales, making the development of robust targeting tools for agroforestry intervention a key priority in agroforestry research.

Agroforestry's contribution to food security and climate change goals

The framework under which agroforestry could contribute to food security, social wealth and climate change alleviation requires a clear understanding of the components and processes that are relevant for sustainable management of benefit flows from ecosystem services in changing agricultural landscapes. Figure 1 suggests factors that significantly impact on the success of agroforestry.

Adoption of agroforestry depends on many management goals, drivers and contextual factors. In most cases, assets related to ecosystem services and to food security are the main motivating factors in agroforestry adoption [8,17]. Agroforestry has also supportive functions, for example, for soil fertility improvement or water recycling [13,26,27], particularly when management techniques such as mulching or conservation agriculture are applied [28]. Agroforestry is therefore often considered as a way to sustainably intensify farming practices for enhanced food security using socially and cost-effective management techniques. Many agroforestry options achieve this through low external input requirements, high recycling rates and crop-livestock integration [29••,30]. They may thus be a viable option for smallholder farmers with limited resources, but where land holdings are small, farmers are often unwilling or unable to spare land for agroforestry establishment (even if this promises higher returns in the long run). Where land holdings are also insecure, farmers are often reluctant to invest in the long-term endeavor of establishing trees that may benefit the next owner of their land rather than themselves. Much research is still needed to determine how and under what circumstances agroforestry or related concepts, such as climate smart agriculture, can contribute to enhancing food security and livelihood resilience in the face of climate change, especially for the poorest segments of rural populations in Africa [12,31,32•].

Figure 1



Framing factors for agroforestry options.

With growing pressures from climate change and demographic development, farmers will need to produce significantly more food on less land. Increasing scarcity of agricultural inputs may further reduce access of African farmers to fertilizers, irrigation and energy-intensive mechanized production approaches, and environmental concerns may restrict their ability to expand cropping areas [19]. Climate change is likely to make it even harder for farmers to cope with these problems.

Agroforestry is often considered a cost-effective strategy for climate change mitigation. Tree-based farming systems store carbon in soils and woody biomass, and they may also reduce greenhouse gas emissions from soils [33,34]. The substantial carbon sequestration potential of agroforestry stems not so much from a high carbon density, but from the large areas that are potentially suitable for agroforestry, including many degraded areas [35]. To date, it is unclear how this potential can be realized. Compared to plantations of forestry species, carbon sequestration in agroforestry is relatively slow [34], so that payments through international carbon finance schemes may often not provide much incentive in low-potential regions, such as the West African Sahel [36,37]. Where biological potentials are higher, potential carbon benefits are often outcompeted by high opportunity costs of sequestering carbon, for example, when land owners are unlikely to forego highly profitable cash crop production for the sake of sequestering carbon [12,38]. Where and under what circumstances carbon finance can make farmers implement agroforestry is an area of active research [39,40].

Depending on the way markets are constructed, part or all of emission reduction achieved will be offset by tradable emission rights in countries with commitments to achieve national emission reduction. Although in most agriculture-based climate change mitigation strategies that do not address underlying drivers, local sequestration successes may be linked to increased emissions elsewhere ('leakage'), this may be less likely for agroforestry interventions, if these interventions simultaneously raise the productivity of food production. Consequently, efforts have been made to ensure that agroforestry receives attention in the context of the Reduced Emissions from Deforestation and Forest Degradation (REDD+) modalities, in which avoidance of such 'leakage' is a key concern. In order to move from the REDD+ approach toward more comprehensive mitigation strategies, more evidence of net mitigation successes at the landscape scale and additional instruments that cover other land uses such as agroforestry are needed. Also, concerns may arise with the practicality of REDD+ in the context of small-holders farmers in Africa, or if REDD+ will have a 'brief life', given many challenges related to its implementation [41].

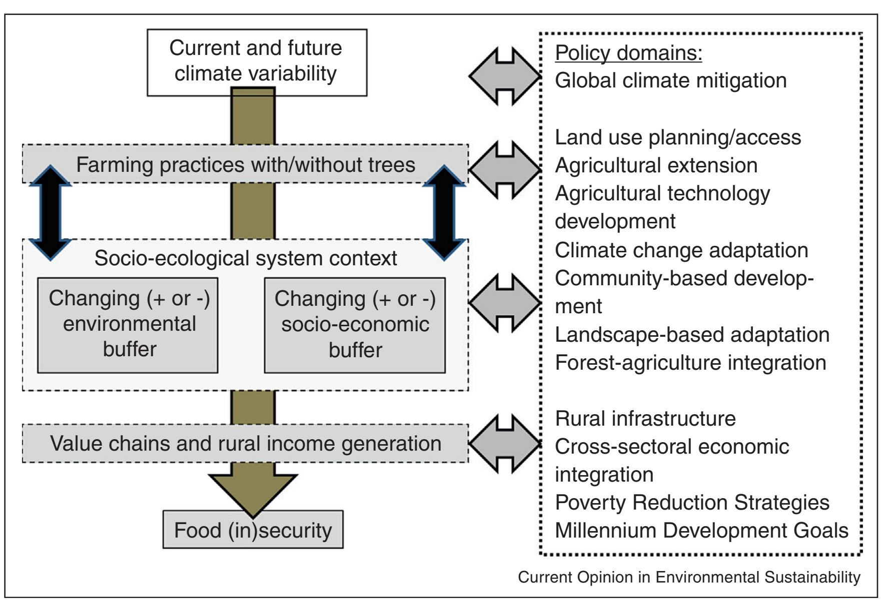
Regarding adaptation of agricultural production to climate change, agroforestry has potential to moderate climate extremes, in particular high temperatures, as well as intra-annual climatic fluctuations. Tree canopies can create a more adequate microclimate for crops and more resilient ecosystems for better food production [8]. On the other hand, a dense tree canopy also reduces incident solar radiation, possibly depressing crop yield potentials. Additional research is needed for guidance on optimum tree cover for climate change adaptation in varied environmental settings, especially in the area of modelling where tools remain inadequate [42].

Although microclimatic effects may convey adaptation benefits to farmers, added resilience through enhanced productivity and farming portfolio effects may be a greater contribution to coping with climate change at the farm level. Establishing agroforestry on land that currently has low tree cover has been identified as one of the most promising strategies to raise food production without additional deforestation [2,23]. The often favourable soil fertility effects of agroforestry are supplemented by additional direct benefits and services that trees on farm provide, such as fuel wood, timber, fruits or fodder. Such services are typically more important to farmers than indirect effects of enhanced soil fertility or avoided deforestation [28]. Since agroforestry may raise and stabilize farm incomes, adaptation benefits are then not so much derived from interventions that target particular climate hazards, but from a general reduction in farmers' vulnerability to shocks through greater human and environmental wealth. A recent paper showed that agroforestry reduced food insecurity during drought and flooding in western Kenya by 25% due to increased income and improved livelihoods [16].

Synergies between food security and climate change mitigation

Climate change mitigation has not traditionally been a driver of farmers' decisions, and it is unlikely to become a major driver in the future. Clearly, sequestering carbon on farms for the sake of climate change mitigation may not be attractive for an African smallholder farmer, especially if mitigation efforts do not lead to short-term increases in income or welfare. African farmers may be very reluctant to sacrifice any part of their often meagre farm incomes to sequester carbon. If such farmers are to contribute to mitigation anyway, carbon-sequestering land use strategies must either be subsidized, to an extent that makes them equivalent to foregone profits from alternative land uses, or they must be profitable in their own right — without any compensation. With biocarbon projects continuing to be challenged to overcome financial, institutional and governance hurdles, the greatest opportunity to

Figure 2



Policy domains interacting with the logical pathway between climate variability (current and future) and food (in) security via land use practices with or without trees.

sequester carbon on a large scale on Africa's farms is through innovations that enhance food security and provide mitigation services as a co-benefit (e.g. increased parkland tree cover, multi-layered farming, intercropping, land sharing practices, among others) [43••,44] (Figure 2).

Agroforestry is one the few land use strategies that promises such synergies between food security and climate change mitigation. It is also less likely than other strategies to negatively affect the provision of non-carbon ecosystem services, such as water cycle regulation [7,33,45] or biodiversity conservation [46], all of which are integral aspects of 'climate-smart agriculture' [47].

Conclusions

Like few other land use options, agroforestry has real potential to contribute to food security, climate change mitigation and adaptation, while preserving and strengthening the environmental resource base of Africa's rural landscapes. It has a key role to play in landscape-scale mitigation schemes under the REDD+ or AFOLU (Agriculture, Forestry and other land uses) concepts. For millions of African farmers whose livelihoods are threatened by climate change and land degradation agroforestry offers a pathway toward more resilient livelihoods.

However, not all agroforestry options are viable everywhere, and the current state of knowledge offers very little guidance on what systems work where, for whom and under what circumstances. The following is a selection from the host of open questions that remain unanswered for most places:

- What tree species work best under given site conditions?
- Which tree-crop-site combinations are characterized by synergistic interactions, which ones by trade-offs?
- What extension methods are most effective for promotion of climate-smart agroforestry systems?
- Which agroforestry systems support healthy, ecologically functional landscapes?
- How can ecosystem service delivery through agroforestry systems be optimized?
- How will agroforestry species respond to climate change?
- Are adaptation benefits from agroforestry greater than those of alternative land uses?
- How, if at all, can smallholder farmers benefit from carbon payments?

This list is by no means exhaustive. In fact, knowledge gaps in agroforestry are greater than the actual body of knowledge on most aspects. It is therefore essential that research efforts on these important cropping systems are intensified, so that future scaling-up of agroforestry can be rooted in robust scientific findings rather than the intuitions of governments and development actors. This special issue addresses some of the current research questions, introduces some innovative ways to conceptualize agroforestry systems and provides an overview of the status quo of agroforestry science, on which future research can build. We hope that this collection of papers will stimulate more research in tree-based farming systems, so that the host of its potential benefits can reach many more farmers throughout Africa in the future.

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