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Climate risk adaptation by smallholder farmers: the roles of trees and agroforestry

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Smallholder farmers are vulnerable to environmental, climate and weather-related stress, including climate change. There is an increase in understanding of the benefits of agroforestry systems both at farm and landscape scales, and that incorporating trees on farms through agroforestry systems has emerged as having the potential to enhance the resilience of smallholders to current and future climate risks including future climate change. Drawing on global examples with a focus on African case studies, this paper demonstrates the versatile roles of trees and agroforestry in reducing smallholder's exposure to climate-related risks. It goes on to identify challenges in the promotion and adoption of agroforestry at the farm and landscape levels as a climate change adaptation strategy. The paper highlights areas for further research, policy and dissemination efforts, and identifies entry points for agroforestry adoption.

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Vulnerability of smallholder farmers to climate change

The projected impact of global climate change, particularly increasing temperatures, rainfall variability, frequency and severity of extreme events, and increasing incidence of pests and diseases will likely affect the agriculture sector [1,2]. Smallholder farmers in developing countries, in particular Sub-Sahelian Africa largely practice rainfed agriculture and forestry, and therefore depend on complex interactions of monsoon systems and local heat and hydrological feedbacks which dictate the temporality and spatiality of rainfall [3–5]. Changing spatial and temporal patterns of temperature and precipitation regimes therefore expose Africa's smallholders and major agricultural production systems to tremendous climate risks, causing crop failure and affecting the livelihood and health of farmers [6–9]. For example, Sub-Saharan Africa is considered highly vulnerable to these impacts with reductions in production exceeding 20% for staples such as maize predicted by mid-century [10,11].

Existing stresses include increasing population pressure on natural resources and decreasing agricultural productivity that further aggravates the vulnerability of smallholder farmers. Decreasing productivity has been brought about by soil degradation, declining soil fertility, and increasing soil erosion [12]. For example, farmers in southern Africa without local support networks were forced to migrate in search of work during periods of food scarcity [13], abandoning their own land and creating environmental pressures in destination sites. To meet nutritional needs in developing countries, the productivity and efficiency of current agricultural land use must increase [14]. Smallholder farmers are therefore faced with the challenge of attaining food security while at the same time ensuring sustainability of their natural resource-base, and struggling to cope with climate-related variability and change.

As climate variability increases and related extreme weather events become more frequent and severe, there is a need to identify adaptation options to assist those most vulnerable to their impacts. Agroforestry is increasingly recognized as a sustainable land use in multi-functional landscapes which enhances farmers' ability to adapt to climate change because of the multiple benefits it delivers including food provision, supplementary income and environmental services [15–18]. This paper explores the science and practice of agroforestry and in highlighting its role as a way to address climate risks, supports the case for its inclusion in current and future rural development policies.

The role of agroforestry in responding to environmental change

An estimated 30% of the world's rural population use trees which are present in 46% of all agricultural lands [19] with 55% of people in sub-Saharan Africa living on land with at least 10% forest cover [20]. Incorporating trees and shrubs in food crop systems help address food insecurity, increase CO_2 sequestration, [19] and reduce vulnerability of agricultural systems [21–24].

In the past, smallholder farmers have responded to environmental changes by gradually changing their agricultural practices and selection of adapted cultivars, drawing from their indigenous knowledge and experience [15]. In this way, the indigenous resilience of smallholder farmers to current and future climate variability will likely improve [25••], if the measures employed are flexible, dynamic and adaptable to further changes in risks and vulnerabilities. Understanding this dynamism, replicating successful approaches and crucially, matching these to the heterogeneous socio-cultural, socio-economic, and ecological circumstances of other smallholder farmers remains a central challenge.

Furthermore, these traditional approaches of mixing crops with trees to reduce risks of crop failures is often overlooked in climate impact and adaptation studies which have tended to focus on the risks posed to staple monoculture crops, for example, millet [26] and teff [27], and are absent when mapping Africa's high risk areas [28,29]. With changing seasonal patterns, controlling planting windows becomes increasingly important as demonstrated by crop-model studies which suggest that optimized combinations of high-yielding annual crops in sequential systems could double the yields of traditional ones across Africa [30].

Conveying the value of trees and agroforestry for adaptation

Evidence from Southeast Asia suggests that policies which encourage the abandonment of traditional agroforestry systems in favor of adopting more intensive annual crops or monoculture plantations because of their perceived economic benefits may be misplaced [31]. Indeed, such a shift has been shown to expose smallholders to greater risk and increase environmental degradation [32]. Instead, incorporating trees into a multifunctional, diverse landscape mosaic and agricultural systems has been shown to deliver multiple benefits including enhanced global and local ecosystem services, biological diversity, food security and smallholder resilience [33–35].

A summary of the socio-economic and environmental benefits of agroforestry systems in the context of reducing risk exposure are found in Table 1 with some highlighted examples discussed below.

Several agroforestry studies have focused on improving soil and water conservation [36], soil physical properties

Table 1

Agroforestry practices adaptation potential roles, benefits and impacts

Agroforestry systems, activities or practices	Ecological functions				Economic roles	Social/survival roles	Sources
	Enhancing water use, storage and efficiency	Soil productivity and nutrient cycling, and soil erosion control	Control of pests and diseases. Buffering against natural calamities	Providing shade and shelter; improving microclimate (shade)	Improvement in farm productivity and profitability; Diversifying income and food sources; Increasing incomes; Spreading income risks; Stabilizing/enhancing livelihoods	Providing multiple food and energy sources during extreme events; Providing social security through sale of trees during crises period; improving nutrition through fruit production	
Agroforestry (in general)	✓	✓	✓	✓	✓	✓	[16,25••]
Multi-storey cropping				✓			[34]
Soil and water conservation							
Alley cropping/hedgerows		✓			✓	✓	[46]
Improved fallows	✓	✓			✓	✓	[25••]
Legume trees, parklands	✓				✓		[30]
Tree-based							
Fertilizer tree system		✓			✓	✓	[16,18,31,32]
Modified Taungya system				✓	✓	✓	[35,36]
Sahelian eco-farm				✓	✓	✓	[25••]
Parkland/scattered tree system		✓		✓			[25••]

[37•,38], and microclimate [25••]. Furthermore, the presence of trees on farm serve as windbreaks and shelter belts, and are used for reconstructing properties damaged during storms [30,39,40]. A study conducted in Western Kenya shows that presence of trees on farms provided a more accessible, safe and stable source of fuelwood for energy and income, particularly benefiting for women [41••]. Agroforestry systems when well designed and properly managed, have some degree of beneficial effect on yield and income and potential for sustained production. For example, fertilizer trees species (FTS) are widely documented to substantially increase maize yields compared to maize production without fertilizer in Zambia [18,32] and across Africa [33]. In addition, maize yields were more stable when grown with *Leucaena* hedgerows than monocropped [42]. The same has been shown for alley cropping system with, for example, maize, peanut, wild jujube [43], and FTS [44].

Existing studies on agroforestry systems have made it easier to choose locally appropriate strategies for maximizing the farm-level benefits based on the production objective of the farmer. However, the multiple roles that trees can play, especially at a landscape scale, are less studied and often do not influence the farmers' adoption of agroforestry [16]. The challenge that needs to be addressed is how to comprehensively assess and factor in the potential of trees in providing environmental services, to achieve more sustainable practices amidst existing climatic and environmental changes.

Making agroforestry systems context specific

The economic value and potential yield of each system will depend on existing biophysical and socio-economic conditions as well as the farmers' familiarity with management practices [45]. A study in West African Sahel, for example, showed that live fence and fodder banks reduced yields the first year but were recovered in the second year [46].

Agroforestry adoption at the farm-scale could be improved in several ways. Ensure that agroforestry dynamics are compatible with local practices, cultural norms and traditions. Concepts such as sustainability, risks, costs and benefits of agroforestry versus current farming systems need to be monitored and made easily understandable to smallholder farmers. Mechanisms behind household decision-making can be improved, such as technical knowledge, accurate climate information and the understanding of agroforestry contribution to buffering against climate risks [18,22,25••]. Lastly, secure land tenure is a proven barrier for agroforestry adoption in southern Africa [35].

Going beyond the farm level

The immediate ecological and economic benefits of agroforestry are more felt at the farm level, but may extend beyond the farm to regional and even global scales [47••]. At the aggregate level, such benefits include biodiversity conservation, watershed management, and carbon sequestration. Various studies have investigated the role of agroforestry in enhancing biodiversity [40,48,49].

An emerging access point for smallholder farmers could come from the increasing interest in the role of agroforestry in climate change mitigation through enhancing carbon sequestration [38,50–52]. Carbon forestry schemes may have attracted almost as many critics as advocates but indisputably they have attracted significant funding and technical support for host communities. The efficacy of such schemes and their contribution to sustainable development and the socio-economic conditions of participants is beyond the scope of this paper. Nonetheless, those schemes which have included the promotion of agroforestry methodologies as a means of engaging farmers have been more successful at providing pro-poor co-benefits to augment often meager carbon payments and supporting farmers' transition to more sustainable land use practices. This is especially true in payment for ecosystem service schemes in Latin America silvo-pastoral agroforestry systems which attracted and supported more vulnerable households [53].

A carbon forestry scheme in Mozambique which promotes almost exclusively agroforestry systems has been the subject of a number of studies. One study found that overall household income was generally increased [54] with another highlighting the role of agroforestry in reducing off farm labor requirements [55]. However, the benefits provided by agroforestry beyond the farm level, that is, at a landscape scale have not yet been fully appreciated in Africa [56,57]. This could therefore represent an entry point for additional support, advocacy and training for already engaged farmers and a source of best practice examples as well as hard lessons learned. Somewhat surprisingly, given what we know about the role of agroforestry in enhancing resilience to climate variability there is a striking paucity of analysis or evidence within the sizeable socio-economic and technical studies relating to carbon forestry projects which demonstrate the climate change adaptation benefits.

Conclusion: outstanding challenges

The examples synthesized and discussed here serve to demonstrate the growing recognition of agroforestry as a tool in helping smallholder farmers adapt to the multiple threats represented by a changing climate. The paper has also highlighted the enduring challenges in four key areas:

Research: There is an increasingly sophisticated understanding of the benefits of agroforestry systems while a deeper understanding of how and under what conditions

smallholder households adopt these systems in response to climatic triggers is still required, both at farm and landscape scales. Where smallholder farmers recognize the benefits of incorporating trees on farms, new approaches to address adoption barriers such as secure land tenure and information gaps, and link agroforestry to climate, food security and development policies, are needed.

Policy: National policies remain incoherent and need to be more explicit if local action is to be supported and benefits realized [58••,59]. Integration of agroforestry principles into existing natural resource and agrarian policies, including those relating to forestry, biodiversity conservation, and water resources would create a more harmonious and encouraging legislative environment [60]. Furthermore, raising the profile of agroforestry in national policy arenas to emphasize its status as a viable and effective system to address the multiple threats of future climate variability will require coordinated advocacy efforts drawing on robust science and practice [61]. Research on agroforestry can contribute to climate proofed policy options that promote short-term and medium-term economic benefits which maintain flexibility while reducing vulnerability.

Dissemination and extension: There remains a need for evidence-based policies, that is, knowing what works best for whom and where should be the basis for appropriate interventions and sharing of learning. What are the modes and mechanisms for collaboration and knowledge exchange among smallholder farmers, policy makers, local extension workers, farmers' organizations to overcome barriers for wider adoption of agroforestry systems and technologies [59]. This could include national and international collaboration between government agencies, non-government organizations and the private sector.

Context specific entry points: Research, training and extension activities linked to supportive policy conditions are all needed to upscale agroforestry adoption. Technical support in identifying suitable agroforestry systems and practices well matched to local biophysical and socio-economic conditions is therefore crucial. Non-government organizations may be well positioned to advocate on behalf of small holder farmers with which they work and for whom they often fulfill the role of under-resourced government agencies [62••]. Private sector organizations can drive the demand for agroforestry products and services (including carbon sequestration) which in turn may lead to increased farmer uptake [56].

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Covering, policy, practice and technical aspects such as crop-soil interactions, this book provides a solid synthesis of current science and practice, highlighting studies in sub-Saharan Africa, Europe and Latin America.