MINI REVIEW

Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture

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Abstract

Addressing the global challenges of climate change, food security, and poverty alleviation requires enhancing the adaptive capacity and mitigation potential of agricultural landscapes across the tropics. However, adaptation and mitigation activities tend to be approached separately due to a variety of technical, political, financial, and socioeconomic constraints. Here, we demonstrate that many tropical agricultural systems can provide both mitigation and adaptation benefits if they are designed and managed appropriately and if the larger landscape context is considered. Many of the activities needed for adaptation and mitigation in tropical agricultural landscapes are the same needed for sustainable agriculture more generally, but thinking at the landscape scale opens a new dimension for achieving synergies. Intentional integration of adaptation and mitigation activities in agricultural landscapes offers significant benefits that go beyond the scope of climate change to food security, biodiversity conservation, and poverty alleviation. However, achieving these objectives will require transformative changes in current policies, institutional arrangements, and funding mechanisms to foster broad-scale adoption of climate-smart approaches in agricultural landscapes.

Introduction

Agriculture lies at the crossroads of climate-change mitigation and adaptation efforts. The agricultural sector is currently responsible for an estimated 13.7% of global greenhouse gas (GHG) emissions (Tubiello *et al.* 2013) and is also a key driver of deforestation which contributes an additional 7–14% of global emissions (Harris *et al.* 2012; Hosonuma *et al.* 2012). At the same time, climate change will have significant negative impacts on many agricultural communities, particularly smallholders and poor farmers who have limited capacity to adapt to adverse shocks, further exacerbating global poverty and food insecurity (Howden *et al.* 2007; Morton 2007). Thus, both mitigation efforts to reduce GHG emissions and adaptation measures to maintain crop yields are of global significance.

Achieving significant progress on both mitigation and adaptation in the agricultural sector will contribute to the success of several multiple international policy initiatives. Mitigation is critical for meeting the overall goal of the United Nations Framework Convention on Climate Change (UNFCCC) to stabilize greenhouse gas concentrations in the atmosphere (United Nations 1992) and, in particular, for reducing greenhouse gas emissions from deforestation and degradation (i.e., through REDD+; Wollenberg *et al.* 2011). Adaptation in agriculture is necessary for meeting the Millennium Development Goals established by the United Nations (http://www.un.org/millenniumgoals/), especially those on eradicating extreme poverty and hunger (Sanchez & Swaminathan 2005). The Aichi Targets of the Convention on Biological Diversity (a set of targets developed for reducing the loss of biodiversity at the global level; CBD 2011) also acknowledge the importance of sustainable management of agriculture (Target 7) and climate-change mitigation and adaptation efforts (Target 15). As a result, significant attention is now being paid to "climate-smart agriculture" which seeks to ensure the food security of a rapidly growing population while adapting to a changing climate and reducing GHG emissions (McCarthy *et al.* 2011; FAO 2013), as evidenced by recent policy conferences on Agriculture, Food Security, and Climate Change in the Netherlands (2010) and Vietnam (2012), the Commission on Sustainable Agriculture and Climate Change (Beddington *et al.* 2011), and new global initiatives on Climate Smart Agriculture (e.g., FAO 2010; World Bank 2011; Vermeulen *et al.* 2012).

Despite the growing recognition of the need to pursue mitigation and adaptation goals in agricultural systems and the current high profile of agriculture and climate change in international policy discussions, most adaptation and mitigation efforts continue to be approached in isolation from each other. Pursuing these activities separately, however, limits the potential to take advantage of synergies and to minimize tradeoffs across actions designed for either adaptation or mitigation benefits. It also leads to potential inefficiencies in the use of funding, and prevents an integrated management approach to agricultural landscapes which could both address climate issues and ensure the provision of food, water, and other ecosystem services (Scherr *et al.* 2012; Sayer *et al.* 2013).

In this article we highlight the opportunities for obtaining synergies between adaptation and mitigation activities in tropical agricultural landscapes and explore how agricultural systems and landscapes can be designed and managed to achieve these synergies. We also identify some of the key scientific, policy, institutional, funding, and socioeconomic barriers to achieving these synergies, and provide preliminary insights into how these barriers can be overcome. We focus our discussion on tropical agricultural systems because these have a higher mitigation potential than temperate systems (Smith *et al.* 2008; Hillier *et al.* 2012), are highly vulnerable to climate change, and are crucial for global efforts to improve food security and alleviate poverty (FAO 2010; Wollenberg *et al.* 2012a).

Climate-change adaptation, mitigation, and potential tradeoffs

A growing body of literature addresses the management practices that can be used to enhance the adaptive capacity or mitigation potential of tropical agricultural systems (e.g., FAO 2010, 2013; Wollenberg *et al.* 2012b). Adaptation options include a wide set of approaches designed to reduce the vulnerability and enhance the adaptive capacity of agricultural systems to climate change. These options include engineering solutions that deal with climate-related risks, breeding for different environmental stresses, developing early warning systems, and establishing crop insurance systems. They also include a range of farm management practices (such as soil and water conservation practices, crop diversification, and improved tillage practices) that make agricultural systems more resilient to climate change, diversify farmer livelihoods and ensure the continued supply of ecosystem services (Howden *et al.* 2007).

Mitigation options for agriculture, in contrast, are generally divided into three broad categories of practices: (1) activities that increase carbon stocks above and below ground; (2) actions that reduce direct agricultural emissions (carbon dioxide, methane, nitrous oxides) anywhere in the lifecycle of agricultural production; and (3) actions that prevent the deforestation and degradation of high-carbon ecosystems to establish new agricultural areas (Smith *et al.* 2007; Wollenberg *et al.* 2012b).

When adaptation and mitigation goals are pursued separately in agricultural systems, as is often the case, tradeoffs may occur over different temporal or spatial scales (e.g., Rosenzweig & Tubiello 2007; Verchot *et al.* 2007; Smith & Olesen 2010). For example, efforts to promote agricultural productivity of individual farms by increasing the use of agrochemicals could maintain crop yields in the face of climate change, but result in greater overall GHG emissions (Kandji *et al.* 2006). Conversely, the promotion of fast-growing tree monocultures or biofuel crops for mitigation purposes may enhance carbon stocks, but potentially reduce water availability downstream and decrease the land available for agriculture (Huettner 2012).

The consideration of tradeoffs across multiple temporal and spatial scales is critical since some tradeoffs will manifest themselves immediately, while others may show a time lag. For example, the use of conservation agriculture (which consists of practices that minimize soil disturbance, maintain permanent soil cover, and diversify crop rotation; Hobbs 2007) often reduces agricultural yields over the short term (3–5 years) but results in greater productivity and carbon sequestration over the long-term (Rusinamhodzi *et al.* 2011).

Potential tradeoffs between adaptation and mitigation activities can often be minimized, and sometimes even avoided, through integrated landscape level planning, an approach that considers adaptation and mitigation goals along with other dimensions such as food security, biodiversity conservation, and poverty alleviation (Biesbroek *et al.* 2009; Sayer *et al.* 2013; Scherr *et al.* 2012). For example, projects that aim to sequester carbon in forest plantations can potentially minimize potential impacts on water and biodiversity by establishing diverse, multi-species plantations of native species, minimizing the use of heavy machinery and pesticides in plantation establishment and management, and locating plantations on degraded lands (Brockenhoff *et al.* 2008; Stickler *et al.* 2009).

Integrating adaptation and mitigation in tropical agriculture

Several management strategies hold particular promise for simultaneously achieving adaptation and mitigation benefits at the plot and farm scale (Table 1). For example, soil conservation practices and the use of conservation agriculture, such as the incorporation of crop residues, use of composts, and minimum tillage, can increase organic carbon in soils, improve soil moisture, and reduce erosion during extreme weather events (Hobbs 2007; Delgado *et al.* 2011). The incorporation of trees in farms through agroforestry systems increases soil carbon stocks and above-ground biomass, while providing shade for protection from rising temperatures, diversifying farmer income and reducing financial risk (e.g., Verchot *et al.* 2007; Matocha *et al.* 2012). Most of these "climate-smart" practices that address both adaptation and mitigation goals are already well known and promoted under the banners of Conservation Agriculture, Agroforestry, Sustainable Agriculture, Evergreen Agriculture, silvopastoral systems, sustainable land management, EcoAgriculture, or best-management practices (McNeely & Scherr 2003; Hobbs 2007; FAO 2010; Garrity *et al.* 2010), but wider adoption of these practices is needed.

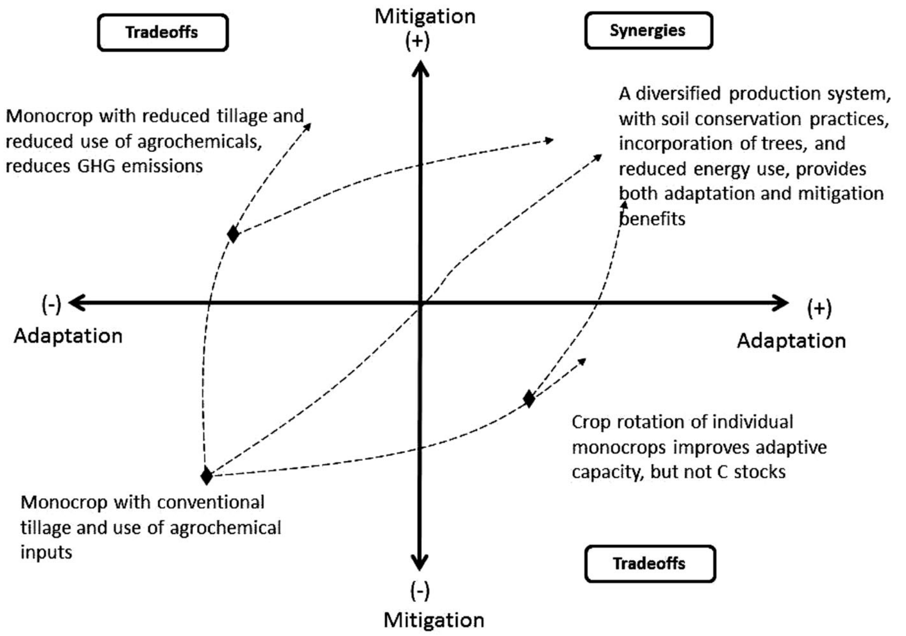
In many cases, it is possible to enhance both the adaptive capacity and mitigation potential of different agricultural systems and landscapes by changing the suite of management practices used. In annual cropping systems, changes from conventional tillage practices and high agrochemical input to soil conservation practices can convert the system from one that either provides only adaptation or mitigation benefits or neither types of benefits, to one that provides both adaptation and mitigation benefits, for instance if more water is captured or if a permanent soil cover increases soil organic matter (Figure 1a). For example, the adoption of conservation agriculture can lead to significant increases in yields of maize, sorghum, wheat, and other crops (up to 20–120% higher than those in conventional agriculture; Kassam *et al.* 2009), due to increased soil fertility, nutrient availability, and water availability. In addition, these systems have been shown to have a higher adaptive capacity to climate change (particularly reduced vulnerability to drought) than conventional systems because their soils have higher infiltration rates and greater moisture-holding capacity; Kassam *et al.* 2009). These systems can also increase carbon sequestration at soils, albeit at a slow rate and not in all situations: Baker *et al.* (2007) estimated that crop rotation systems in conservation agriculture accumulated 11 tons of carbon per hectare after 9 years.

In perennial cropping systems, such as coffee or cocoa, the inclusion of a diverse, well-managed shade canopy and appropriate soil management practices can similarly confer both adaptation and mitigation benefits (Figure 1b). Maintaining a diverse shade canopy of multifunctional trees in cocoa systems helps maintain soil organic matter and soil fertility, improves the stability of cocoa production, diversifies farmer livelihoods by providing sources of timber, fruits and other nontimber products, and provides ecosystem services at the landscape level (Tscharntke *et al.* 2010; Somarriba & Beer 2011; Somarriba *et al.* 2013). Cocoa agroforestry systems also maintain high levels of plant biomass and soil carbon

Table 1 Examples of agricultural practices and actions that can confer adaptation and/or mitigation benefits at the plot, farm and/or landscape scale

Scale	Practices that primarily confer adaptation benefits	Practices that provide BOTH adaptation and mitigation benefits	Practices that primarily confer mitigation benefits
PLOT	• Use of new crop varieties or livestock breeds that are drought-tolerant, or bred for specific environmental stresses • Adjustments in irrigation practices and systems • Changes in timing of planting, pruning or harvesting • Adjustments in cropping sequence and timing of irrigation or application of fertilizers and pesticides • Changes in timing, duration, and location of animal grazing • Conservation of crop and livestock genetic diversity	• Integrated soil and water conservation efforts • Incorporation of organic fertilizers and cover crops • Reduced or zero tillage • Maintenance of crop residues • Breeding crop varieties for shade tolerance • Use of agroforestry	• Reduced or more efficient use of fertilizers and pesticides • Adjustments in the type of feed provided to cattle • Reduced frequency or extent of fires • Reduced or more efficient use of machinery and fossil fuels • Improved management of cultivated wetland rice areas to reduce methane emissions
FARM	• Changes in rotation or production systems • Improved water harvesting and retention through ponds, dams, etc. • Increased water use efficiency through improved irrigation practices • Conservation of agrobiodiversity • Use of seasonal and multiyear forecasting • Farm insurance or crop or livestock insurance	• Diversification of crops and livestock systems on the farm • Soil conservation practices, including terracing and land contouring • Improved residue management and use of cover crops • Integrated nutrient management • Use of agroforestry • Use of silvopastoral systems (e.g., trees in pastures, live fences, fodder banks) • Appropriate animal rotation practices • Use of conservation agriculture (i.e., minimal soil disturbance, maintenance of mulches, use of crop rotations and intercropping, integrated pest management) • Use of multicropping, intercropping, and crop rotations	• Reduced or more efficient use of agrochemicals • Planting of biofuels and trees for fuel wood • Planting of fast-growing tree plantations • Reduced use of machinery and fossil fuels • Generation of biogas from manure • Use of improved feeding practices for livestock
LANDSCAPE	• Maintenance of habitat connectivity to ensure pollination and pest control • Development of water collector systems, irrigation infrastructure and other engineering solutions to reduce risks of floods, water scarcity, and other climate-related risks • Targeted location of intensive livestock production within the landscape to reduce water contamination • Diversification of farmer income options	• Land-use planning at the landscape level for multiple objectives • Maintenance of landscape diversity—including a mosaic of agricultural land and natural habitat • Conservation and restoration of riparian areas within the agricultural landscape • Conservation and restoration of remaining forest habitat in the surrounding landscape—including formal and informal protected areas • Establishment of agroforestry and silvopastoral systems • Sustainable intensification of livestock production and crop production in some areas, to reduce pressure on fragile areas • Increases in the duration of fallow periods in shift and burn cultivation • Restoration of degraded or fragile lands • Conservation and restoration of wetlands and peat lands • Reduced expansion of cropland into remaining natural habitat	• Planting of biofuel feedstock • Careful management of fires

(a) Annual crop (corn)



(b) Perennial crop (cocoa)

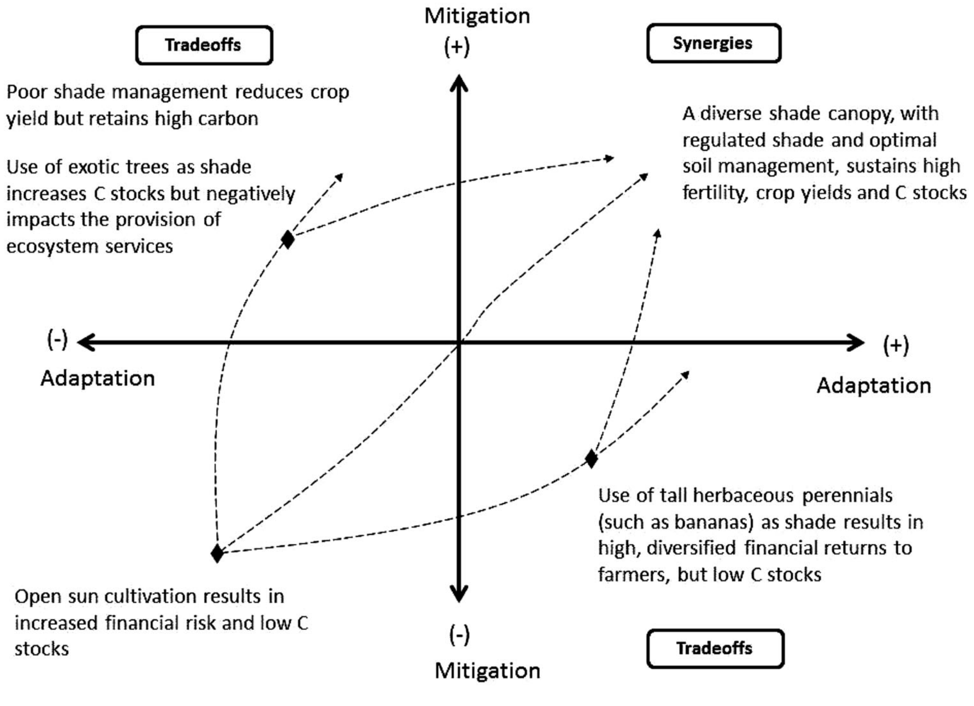


Figure 1 Diagrams showing how crop or livestock production systems can be managed to achieve synergies between adaptation and mitigation outcomes. In each diagram, the lower left quadrant indicates a system that provides minimal mitigation benefit and is not adapted to climate change. The upper left quadrant shows a system that has potentially high mitigation potential but little adaptive capacity, whereas the lower right quadrant shows a system that is adapted to climate change but releases signficant green house gases or has low carbon stocks. The upper right quadrant indicates systems where both adaptation and mitigation benefits are achieved. Arrows illlustrate how changes in management can move the system from one state to another.

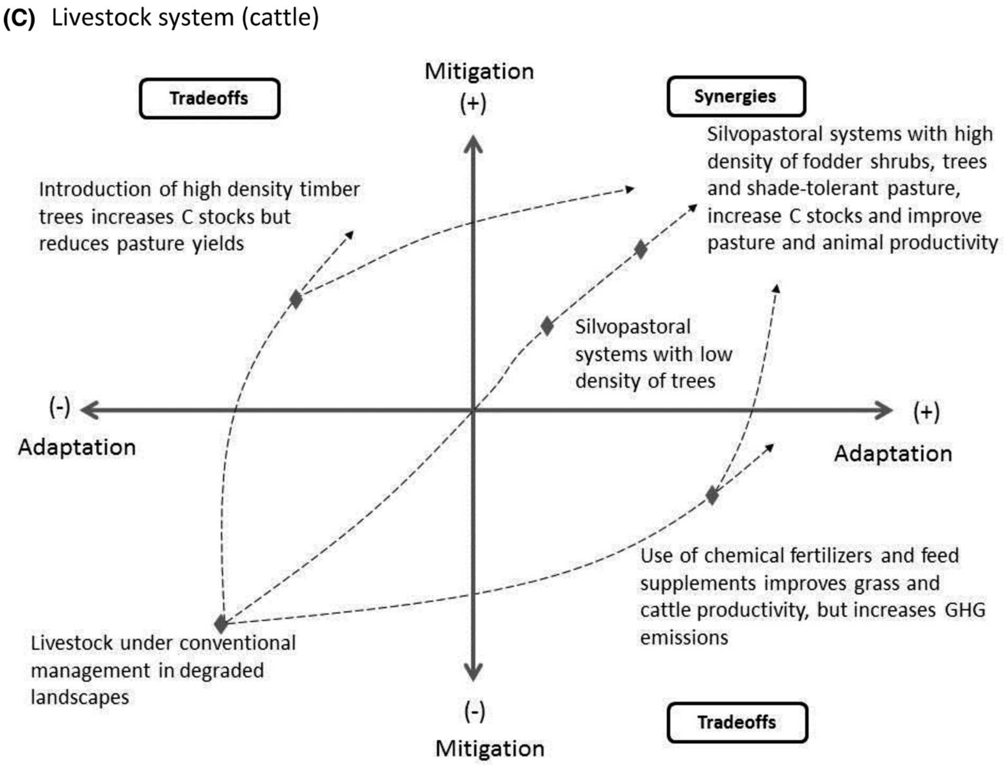


Figure 1 Continued

storage, providing mitigation benefits. For example, traditional cocoa agroforestry systems in Central America have 117 ± 47 Mg/ha of total carbon in the soil and above-ground biomass, and accumulate between 1.3 and 2.6 of Mg C/ha/year in above-ground biomass annually (Somarriba *et al.* 2013).

In livestock production systems, degraded pastures can be gradually converted to diverse silvopastoral systems, with fodder trees and timber trees interspersed within pastures of shade-tolerant grasses, which improve the overall adaptive capacity of the system, while also greatly enhancing carbon stocks (Murgueitio *et al.* 2011; Calle *et al.* 2013; Figure 1c). For example, in Colombia, the adoption of intensive silvopastoril systems (systems that include the high-density cultivation of fodder plants [>10,000 plants/ha], timber trees and improved grasses for cattle production) at the landscape scale has been shown to increase cattle stocking rates (from <1 animal ha^{-1} to 3 ha^{-1}), increase net per hectare income farmer productivity (by 132%), enhance biodiversity levels, reduce the use of herbicides and fossil fuels (by 43%), release areas for biodiversity protection and sequester additional carbon above-ground (World Bank 2008; Murgeitio *et al.* 2011; Calle *et al.* 2013).

Synergies at the landscape level

The landscape scale also has many important opportunities for synergies between adaptation and mitigation efforts (Scherr *et al.* 2012). Landscape-level interventions such as the conservation and restoration of riparian areas or wetlands can help regulate water flows to agriculture, while storing carbon in peat and sediments (e.g., Schultz *et al.* 2004). Similarly, the conservation and management of tree cover (e.g., hedgerows, woodlots, riparian forests, forest fragments), both within the farm and in the surrounding landscape, improves landscape connectivity, conserves biodiversity, maintains critical carbon stocks, and ensures the provision of ecosystem services (e.g., pollination, pest control, and water regulation) that support agriculture (Tscharnkte *et al.* 2005; Schroth & McNeely 2011; Sayer *et al.* 2013).

In some cases, adaptation and mitigation benefits will only be possible if action is taken across an entire landscape. For example, efforts to control flooding downstream depend on the adoption of sustainable land management practices (such as the use of terraces, permanent soil cover, and conservation of riparian forests) that improve the water holding capacity and infiltration by upland farmers (Brauman *et al.* 2007). A nice example of the potential for adaptation and mitigation synergies at the landscape level is the widespread use of Farmer Managed Natural Regeneration (FMNR) in Ethiopia, Niger, and elsewhere in Africa (Brown *et al.* 2009; Garrity *et al.* 2010). As of 2008, approximately 4.8 million hectares of Faidherbia-dominated farmlands had been generated in Niger through FMNR (Reij *et al.* 2009). In this approach, farmers encourage the systematic regeneration of existing vegetation by regrowing and managing trees and shrubs from felled stumps, sprouting root systems, or self-sown seeds. The adaptation benefits for farmers include income diversification, water regulation (improved infiltration), possible protection from landslides, and increased fodder and fuel wood supply, while mitigation benefits include enhanced storage of carbon above and below-ground (Garrity *et al.* 2010). For example, the Humbo Community-Based Natural Regeneration Project in Ethiopia, which involves the regeneration of 2,728 ha of degraded native forests through FMNR, is expected to sequester in the order of 60 tCO_2 ha^{-1} over the initial 10 years of the project (Brown *et al.* 2009).

Synergies can also arise at the landscape level through the intentional planning of landscape structure and composition (Biesbroek *et al.* 2009). For example, the strategic location of windbreaks across an agricultural landscape can help protect crops and livestock from wind stress during the dry season, while also reducing carbon loss from soil erosion (Jindal *et al.* 2008). Diversification of the agricultural landscape (e.g., through the use of different crops, crop rotations, fallows, agroforestry, and mosaics of crop land and tree cover) is key for pursuing adaptation since it reduces the risks related to climate impacts on particular agricultural systems, enhances the provision of ecosystem services, and can potentially increase landscape carbon stocks if it includes the conservation or establishment of high-biomass systems (Tscharntke *et al.* 2005; Kremen & Miles 2012; FAO 2013).

Barriers to integrating adaptation and mitigation activities in agricultural landscapes

Despite the high potential for synergies between adaptation and mitigation activities, many barriers still prevent the widespread adoption of climate-smart landscapes (Table 2). A primary technical barrier is the lack of quantitative evidence on how different management practices, systems, and landscape configurations affect mitigation and adaptive benefits, as well as agricultural yields, food security, biodiversity conservation, and ecosystem services. For example, Lobell *et al.* (2013) demonstrated that adaptive measures to maintain agricultural productivity by 2050 could result in landscapes that save about 15 GT CO_2e, which indicates that policies focused on adaptation alone can have significant mitigation cobenefits. More analyses are needed to demonstrate when and where pursuing adaptation and mitigation simultaneously is more beneficial and cost-effective than implementing them separately. It is also important to develop, pilot, and implement landscape-level indicators (e.g., of agricultural production and resiliency, adaptive capacity, mitigation potential, ecosystem services, and human wellbeing) that can track the suite of synergies or tradeoffs that result from different agricultural development scenarios and be used to inform decision-making (Sachs *et al.* 2010).

Multiple policy and institutional barriers also impede the integration of adaptation and mitigation goals within agricultural landscapes. At both the international and national levels, adaptation and mitigation are addressed through different processes, discussed in parallel policy debates that are rarely linked, led by distinct ministries or institutions, and involve different constituencies and funding sources (Verchot *et al.* 2007; Locatelli *et al.* 2008, 2011). For example, mitigation is primarily driven by international agreements (e.g., the Kyoto Protocol of the UNFCCC) and ensuing national public policies (and to a lesser degree by unilateral or voluntary action), whereas most adaptation is focused on local or national actions designed to minimize climate-change impacts on local communities (Klein *et al.* 2007; Biesbroek *et al.* 2009). In addition, existing international policy mechanisms address either mitigation or adaptation, but not both (e.g., the Clean Development Mechanism does not consider adaptation, while the Cancun Adaptation Framework does not explicitly mention the linkages between adaptation and mitigation; Locatelli *et al.* 2011). Within a given country, climate-change policy is rarely consistent with other sectoral polices: for example, in Indonesia, policies that promote the expansion of palm oil (both for food and biofuel production) into new areas often conflict with climate-change policies designed to reduce emissions from deforestation and degradation (Pacheco *et al.* 2012). Meanwhile, policies that support conventional agriculture (with high use of fossil fuel and synthetic inputs) often prevail over those that support sustainable and climate-smart practices (Mattison & Norris 2005). In addition, development policy planning often is short-term (typically in 5–10 year cycles), whereas the integration of adaptation and mitigation goals requires longer term planning horizons (Biesbroek *et al.* 2009).

The persistence of separate, uncoordinated funding streams for adaptation and mitigation is another key constraint (Buchner *et al.* 2012; FAO 2013). Climate finance comprises a variety of sources including the UNFCCC, UN organizations or programs, multilateral development banks, bilateral public funding channels, compliance and

Table 2 Barriers to and potential solutions for integrating adaptation and mitigation goals and activities

	Barriers	Solutions
• Policies and Institutions	• Adaptation and mitigation agendas addressed through different policies, discussed in policy debates rarely linked or coordinated, led by distinct ministries and participated in by different constituencies • Policies supporting conventional agriculture practices dominant over those supporting climate-smart agricultural strategies • Policy planning is short-term, whereas the integration of adaptation and mitigation goals requires long-term planning	• Develop NAPAs,NAMAS and REDD+ strategies that are synergistic[a] • Secure high-level commitments to support conservation agriculture, agroforestry, and other climate-smart practices • Promote multistakeholder planning across local, regional, national, and business interests • Raise awareness among policy makers and other decision makers about agricultural systems that meet adaptation and mitigation goals • Promote landscape governance and resource tenure reforms that facilitate and incentivize planning for landscape management • Strengthen local institutions and extension services • Clarify agriculture's role within the context of REDD+
Funding	• Adaptation and mitigation funds typically come from different sources and are not coordinated • Competition for funding between mitigation and adaptation activities • Difficulties in access to capital and technical information by farmers, particularly smallholders, to adopt new practices and diversify agricultural landscapes	• Develop more diverse funding approaches–ecocertification schemes, Payments for Ecosystem Services, philanthropic investments, government funding, private funding—to support climate-smart agriculture, and modify the design of these instruments to ensure integration • Ensure carbon finance initiatives promote the adoption of best practices that integrate mitigation and adaptation goals • Encourage donors (bilateral and multilateral organizations, private sector, foundations) to finance investments in agricultural systems with adaptation and mitigation goals • Promote strategies that include adaptation as a precondition for obtaining carbon finance for mitigation projects (e.g., in the FCPF, UN REDD, CDM or private sector)[b], and vice versa for adaptation projects • Ensure that agriculture is eligible for support from both existing and future climate change funding mechanisms
Research, Training & Technical Capacity	• Decline in financial support for agricultural research, extension services, and university programs limit of transition to climate-smart practices • Limited quantitative evidence on potential cobenefits and tradeoffs of adaptation actions on mitigation and vice versa	• Develop tools for policymakers and other decision-makers to visualize the potential outcomes of different agricultural strategies on mitigation and adaptation, food production, energy, income, and other related objectives • Promote additional research and development on climate-smart agriculture by universities, state and federal research, and extension services • Provide evidence of where and when linking adaptation and mitigation is more beneficial and cost-effective than doing each one separately • Develop indicators to measure the adaptive capacity of farming systems and the impacts of different management practices on productivity, farm sustainability, food security, income, biodiversity conservation, and ecosystem service provision
Socioeconomic	• Poverty, culture, income levels, education, institutional capacity, and land tenure impact the effective adoption of different agricultural practices and land-use decisions by farmers • Farm subsidies and national level policies do not incentivize farmers to adopt conservation agriculture and integrated landscape management • High investment, risks for food security and household well-being, and the lack of knowledge and technical support limit farmers to participate in conservation agriculture	• Promote national-level policy and institutional changes to ensure that farmers have the resources and technical capacity to adopt climate-smart agricultural practices • Encourage and support landscape-level governance systems and resource tenure arrangements at the farm and community levels that enable the integration of adaptation and mitigation strategies • Encourage donors to support local-level efforts, especially farmer led initiatives, that integrate adaptation and mitigation efforts

[a] NAPAs are National Adaptation Programmes of Action, NAMAS are Nationally Appropriate Mitigation Actions.

[b] FCPF is the Forest Carbon Partnership Facility, UNREDD is the United Nations Collaborative Programme on Reducing Emissions from Forest Degradation in Developing Counties, CDM is the Clean Development Mechanism.

voluntary carbon markets, private sector investment, and philanthropy (FAO 2013), with the private sector being the greatest single source (accounting for approximately 74% of global climate finance; Buchner *et al.* 2012). Mitigation activities are typically funded by the private sector and carbon finance, whereas adaptation measures tend to be supported by public funds, NGO's and donors interested in poverty alleviation, food security, or disaster relief (Schalatek *et al.* 2012; Lobell *et al.* 2013). This traditional separation of funding sources (and funding eligibility criteria) has created silos in the implementation of adaptation and mitigation measures on the ground (Schalatek *et al.* 2012), and hindered the adoption of integrated landscape-level approaches (FAO 2013). In addition, climate finance has disproportionately focused on mitigation and only a small portion of climate finance has gone toward agriculture, forests, or land use (e.g., of the 343–385 billion dollars of global climate finance in 2010/2011, only an estimated 11.8 billion went to REDD+; Buchner *et al.* 2012). Although funders are starting to recognize the importance of combining adaptation and mitigation activities (e.g., GEF 2012), funding for climate-smart agriculture approaches currently falls far below what is needed (FAO 2013). A related constraint is the ongoing decline in financial support for agricultural research, extension services, and university programs, which means that the capacity and funds needed to promote the transition to "climate-smart" practices are often lacking (FAO 2010, 2013; McCarthy *et al.* 2011).

Socioeconomic factors also limit the widespread implementation of climate-smart agriculture, even where policy is appropriate and funding is sufficient. Poverty, cultural factors, income, education, access to markets and credit, investment costs, institutional capacity, and lack of land and tree tenure, among others, are all known to affect the effective adoption of sustainable agricultural practices and farmer land-use decisions (McCarthy *et al.* 2011; Reid *et al.* 2012). In many cases, the lack of clear land or tree tenure makes it difficult for farmers to adopt sustainable agricultural practices (Hauswirth *et al.* 2012; Stringer *et al.* 2012). For example, the large-scale adoption of FMNR in Niger only occurred after there was an institutional change in tree tenure from state ownership to local ownership (Brown *et al.* 2009). Farmer adoption of integrated approaches is sometimes also limited by the initial investment costs needed to implement new practices or systems, potential short-term risks to household food security, and the lack of access to technical support and information (McCarthy *et al.* 2011; Wollenberg *et al.* 2012b). Another key consideration is that interventions at the landscape level usually require multistakeholder negotiations or collective actions in order to establish a common agenda and develop agreed-upon plan for land use and management (Scherr *et al.* 2012; Sayer *et al.* 2013). Strong institutions that have the appropriate technical, administrative, and financial capacity and use an integrated, participatory approach to landscape management are needed to both develop and manage these processes (Hauswirth *et al.* 2012).

Recommendations for how to overcome these barriers

While the current barriers to integrating adaptation and mitigation efforts in agricultural landscapes are significant, these barriers could potentially be overcome through a combination of targeted scientific research, policy and institutional reforms, and changes in funding modalities. The appropriate set of opportunities for overcoming existing constraints to climate-smart landscapes in a given location will depend on the political, socioeconomic, and agroecological context, so the following overview should be considered a menu of potential opportunities, rather than a universal approach.

One opportunity for fostering greater adoption of climate-smart landscapes is to ensure that there is a strong scientific evidence and sufficient technical guidance to identify the best options for changes in agricultural systems and landscapes (Scherr *et al.* 2012). Innovative, new tools (including mapping, scenario analyses, and simulation models) are needed to assess and visualize the potential impacts of alternative agricultural development pathways (e.g., different systems, spatial arrangements, and management strategies) on adaptation, mitigation, and other goals, clarify potential synergies and tradeoffs over different temporal and spatial scales, and assess related economic costs (Beddington *et al.* 2012; FAO 2013). New efforts by the CGIAR (http://ccafs.org; Vermeulen *et al.* 2012), the Millennium Villages Project (Palm *et al.* 2010), FAO (FAO 2013) and Vital Signs (http://vitalsigns.org/) to understand and monitor the agronomic, social, economic, and ecological impacts of different agricultural development scenarios in particular landscapes are important steps in this direction, but more is needed. New global monitoring systems that integrate real-time information about agricultural production, forest cover, ecosystem services, markets, agricultural prices, and human wellbeing in near real-time would also be particularly useful in informing decision-making (Beddington *et al.* 2012). There is also a need for more participatory, action-oriented research with farmers to better understand which practices and landscape configurations generate resiliency and mitigation benefits in different agroecological and socioeconomic contexts (FAO 2013).

At the policy and institutional level, governments could promote greater coherence, coordination and integration among adaptation and mitigation efforts and mainstream climate-smart agriculture into broader public policy, expenditures, and planning processes (FAO 2013). For example, governments can ensure that Nationally Appropriate Mitigation Actions (NAMAs), National Adaptation Programmes of Action (NAPA), and other national or state climate strategies are complementary and apply an integrated landscape approach to agriculture (FAO 2013). They could also require that vulnerability assessments (which are often used as a tool for determining adaptation priorities) consider the potential mitigation outcomes of any adaptation activities, and conversely that any mitigation projects take measures to ensure adaptation benefits (Locatelli *et al.* 2011). New agricultural investments can be screened for their degree of "climate smartness" using simple tools such as those developed by the FAO (FAO 2012b). Governments can also set up policy frameworks, institutional arrangements, and planning processes that support the integration of adaptation and mitigation goals in agricultural landscapes, and remove public policies or subsidies to conventional farming practices that contribute little to adaptation or mitigation (FAO 2012a, 2013). A central—and particularly difficult—challenge is for governments to ensure climate-smart agriculture is integrated not only into climate-change policies, but also economic development strategies, food security policies, safety net programs, poverty reduction strategies, and related policies (Beddington *et al.* 2012; FAO 2013). Governments can also help promote the broad-scale adoption of climate-smart agriculture by ensuring farmers have the financial resources and technical capacity to adopt climate-smart practices, raising investment in sustainable agriculture research and development, revitalizing agricultural extension services, and securing land rights so that long-term investments in sustainable agriculture are possible (FAO 2010; Beddington *et al.* 2012).

There is a similar need to mainstream climate-smart agriculture in international climate-change policy, and to give more consideration to agriculture not only as a driver of deforestation, but also as a potential source of mitigation (Murphy & Boyle 2012). While many policy makers present at the climate-change negotiations in Doha (2012) highlighted the key role of agriculture in both adaptation and mitigation, and raised the possibility of including agricultural land uses in REDD+ (http://blog.ecoagriculture.org/2012/12/13/redd.cop18; FAO 2012a), little progress has been made. It is critical that a work program on mitigation and adaptation in agriculture be established within the UNFCCC process (Beddington *et al.* 2012) and that the current ambiguity regarding agriculture's role within the context of REDD+ be resolved (Kissinger 2011).

Governments, funding agencies, donors, and the private sector could also adjust existing financial mechanisms to require both adaptation and mitigation outcomes and use these metrics to track performance. For example, the inclusion of adaptation cobenefits could be established as precondition for obtaining carbon finance for mitigation projects (e.g., FCPF, UNREDD program, CDM or private sector) and conversely, adaptation projects funded by UNFCCC adaptation funds (or future similar funds) could be required to demonstrate mitigation benefits as a requisite for funding. Certification schemes for carbon projects, such as the Verified Carbon Standard (VCS 2013) and the Climate, Community and Biodiversity (CCB) Standard (CCBA 2008), could also be modified to require that mitigation projects provide adaptation cobenefits. The CCB standards currently do not require that forest carbon project generate adaptation cobenefits, but include these cobenefits as an "optional criteria" for achieving the gold level of certification (CCBA 2008). In addition, new funding mechanisms or modalities could be created specifically to promote integrated landscape management approaches that deliver adaptation, mitigation, and food security goals. Climate-smart agriculture could also be funded through payment for ecosystem services schemes that include agriculture (e.g., Pagiola *et al.* 2007) or the ecocertification of sustainably managed agricultural products or landscapes (e.g., Philpott *et al.* 2007; Ghazoul *et al.* 2009).

Conclusions

There are significant opportunities to pursue adaptation and mitigation goals simultaneously in tropical agriculture and to adopt integrated landscape approaches that contribute to climate-change goals, food security, ecosystem service provision, and other goals. While there is no one general formula for capturing synergies between adaptation and mitigation, their joint consideration in landscape planning, research, technical support, government policies, and funding mechanisms would significantly help to achieve this goal. A renewed and strengthened commitment to sustainable agriculture, conservation agriculture, agroforestry, and other best management practices for agriculture, as well as an increased focus on integrated landscape management, would help to promote tropical agricultural systems and landscapes that have enhanced adaptation and mitigation potential, while contributing to food security, poverty alleviation, and biodiversity conservation across the tropics.

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