Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation

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Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation

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Abstract

There are a wide range of agriculture-based practices and technologies that have the potential to increase food production and the adaptive capacity of the food production system, as well as reduce emissions or enhance carbon storage in agricultural soils and biomass. However, even where such synergies exist, capturing them may entail significant costs, particularly for smallholders in the short-term. In this paper, we provide a brief review of the adaptation and mitigation benefits from various practices, and then focus in detail on empirical evidence concerning costs and barriers to adoption, both from household and project-level data. Findings indicate that up-front investment costs can be a significant barrier to adoption for certain investments and practices, and furthermore, the evidence also supports the hypotheses that opportunity and transactions costs across a wide range of investments and practices. Additionally, potential synergies between food security, adaptation and mitigation opportunities, as well as costs, can differ substantially across different agro-ecological zones, climate regimes, and historical land use patterns.

1. Overall context: climate change and agricultural households

Climate change and food security are two of the most pressing challenges facing the global community today. Improving smallholder agricultural systems is a key response to both. The State of Food Security in the World 2010 report estimated that the number of chronically hungry people in the world has reached a total of 925 million people (FAO 2010). About 75 percent of the worst-affected people reside in rural areas of developing countries, their livelihoods depending directly or indirectly on agriculture (FAO 2009). Strengthening agricultural production systems is a fundamental means of improving incomes and food security for the largest group of food insecure in the world (World Bank 2007; Ravallion and Chen 2007). As the key economic sector of most low income developing countries, improving the resilience of agricultural systems is essential for climate change adaptation (Conant 2009; Parry et al. 2007; Adger et al. 2003). And, improvements in agricultural production systems offers the potential to provide a significant source of mitigation by increasing carbon stocks in terrestrial systems, as well as emissions reductions through increased efficiency (FAO 2009; Paustian et al. 2009; Smith et al. 2008).

Today nearly 1 billion people, out of a world population of 6 billion, live in chronic hunger (Bruinsma 2009). Most of these are directly or indirectly dependent on agriculture. Growth in population is expected to result in even greater pressure on the smallholder agriculture sector with the largest increases expected in areas of high food insecurity and dependence on agriculture particularly in South Asia and sub-Saharan Africa (Schmidhuber and Tubiello 2007). At the same time, nearly all researchers conclude that, though average global crop production may not change dramatically by 2050, certain regions may still see average production drop and many more are likely to face increased climate variability and extreme weather shocks even in the near term[1] (c.f. IPCC 2001 and 2007; Rosenzweig and Tubiello 2006). With respect to those areas that currently suffer from a high degree of food insecurity, Lobell et al. (2008) studied the potential crop impacts in 12 food-insecure regions of the world and found that climate change could significantly impact agricultural production and food security up to 2030 particularly for sub-Saharan Africa and South Asia due to both changes in mean temperatures and rainfall as well as increased variability associated with both. Changes in pest and disease patterns could also significantly impact agricultural production (Lobell 2008). In particular, parts of South Asia and Sub-Saharan Africa are expected to be hardest hit, with decreases in agricultural productivity between 15-35 percent (Stern 2006; Cline 2007; Fisher et al. 2002; IPCC 2007). And, these are precisely the same regions that already exhibit high vulnerability to weather shocks, meaning that increasing the adaptive capacity of agricultural systems of these regions is required not only to meet Millennium Development Goals (MDGs) in the near future, but also to ensure that such gains are not lost where negative climate change impacts increase in the future.

Over the last two years, there has been a considerable increase in attention given to the role the agriculture sector in developing countries must play in order to meet food security needs and achieve the MDGs, culminating in commitments of US$20 billion over three years for agriculture sector development. At the same time, the Copenhagen Accord resulted in commitments for fast track funding approaching US$30 billion for the period 2010-2012 and the goal of mobilizing an additional US$100 billion annually by 2020 to help developing countries respond to climate change including both adaptation and mitigation. These actual and potential increases in financial resources

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[1] Antle et al. (1999) simulated changes in dryland grain production in Montana due to projected climate changes; model results show that impact on mean returns by 2030 were ambiguous (-11% to +6%), but that variability increased under all scenarios – both with and without adaptation scenarios.

create a critical opportunity to move agricultural systems in developing countries to more productive and sustainable levels, while addressing climate change.

However, there is also a considerable challenge in achieving an effective use of these funds. Key gaps in knowledge on the tradeoffs and synergies between food security, adaptation and mitigation that are generated by various transformation pathways for smallholder agriculture and the potential impacts of policies on achieving these three objectives need to be addressed. In particular, as we argue more fully below, very rosy net present value figures for many sustainable land management (SLM) practices, that increase carbon sequestration and reduce emissions found in such sources as McKinsey (2009) are not likely to be relevant in the most developing country contexts, since they do not capture the significant financing barriers associated with these practices and appear to be seriously underestimating both direct and indirect costs of adoption.

In addition, knowledge needed to identify key policy and institutional arrangements that support synergistic smallholder transformations is very thin, as are practical assessments of the potential for linking mitigation finance to smallholder agricultural transformations. In this paper, we synthesize the empirical literature on smallholder adoption of SLM practices that have been promoted to increase yields and reduce yield variability through more resilient farming systems, and which also produce mitigation benefits, primarily through increased soil carbon sequestration. In particular, we highlight empirical evidence on the costs and barriers to adoption, including opportunity, transactions, and risk costs of adoption. Because of the vast amount of literature that might be broadly applicable, we focus heavily, though not exclusively, on empirical evidence from African countries. This work is complemented by a separate companion piece (Branca et al. 2011), where we synthesize a wide range of empirical evidence on the benefits of SLM for food production, adaptation and mitigation.

The remainder of the report is organized as follows. In the second section, we broadly review the types of costs and barriers that often hinder adoption of SLM techniques and practices. In the third section, we briefly review the empirical literature on potential climate change adaptation and mitigation benefits to specific SLM practices and investments for three broad categories of activities (which can and do overlap): Agroforestry, Soil and Water Conservation, and Grazing Land Management. The review of benefits is then followed by an in-depth examination of empirical literature that identifies costs and barriers faced by households. The household-based evidence often identifies barriers to adoption, but rarely provides monetary cost figures. In the fourth section, we review project-based information on costs of implementing various SLM-based projects. In the fifth and final section, we give concluding observations.

2. Overview of costs and barriers to adopting climate smart sustainable land management practices and investments

There are five broad categories of costs/barriers identified in the literature associated with the adoption of SLM practices and investments; investment costs, variable and maintenance costs, opportunity costs, transaction costs, and risk costs.

Investment costs for SLM include expenditures on equipment, machinery, or for materials and labour required to build on-farm structures.

Variable and maintenance costs are recurrent expenses needed to either undertake an SLM practice, such as purchase of seeds, fertilizers or additional hired labour, as well as periodic costs associated with maintaining SLM structures, and repayment costs where credit has been obtained.

Opportunity costs of household assets are costs associated with allocated own factors of production to SLM activities, instead of to other uses. In many cases, land allocated to SLM will have the greatest opportunity costs, but own labour, and as we shall see below, crop residues may also have relatively high opportunity costs. Returning to land, the alternative crop income that producers forego to adopt certain SLM practices or investments, can be quite high in the initial phase of adoption, and can also extend for quite some period thereafter. Even if opportunity costs are negative over a longer term horizon (say 20 years), it is important to consider them in the short run as they are certainly an important barrier to adoption, particularly in subsistence economies where credit markets are absent or thin.

Transaction costs include search, bargaining and negotiation, and monitoring and enforcement costs. In the current empirical literature, search costs associated with searching for and processing information on various potential SLM techniques that might be adopted are identified as significant barriers to adoption. Additionally, where necessary, SLM inputs or implements are described as not being available, we can consider that the search costs, including costs of travel, are simply too high to be practicable. With respect to bargaining and negotiation, while experience with carbon-credit market schemes and “payments for environmental services” programmes is still fairly limited, entering into such agreements will entail bargaining and negotiation costs, which may be quite high for an individual farmer. Another often-unaccounted-for cost to the farmer that would fall under this category is participation in donor or NGO-funded projects that often require time and monetary commitments above those associated with SLM-specific costs. Finally, for SLM activities that require collective participation – such as community-level investments in trees, agroforestry, and soil and water conservation structures, or management of communal pastures – monitoring and enforcement costs can also be key factors constraining adoption at this level.

Risk costs, in areas where insurance markets or mechanisms are thin or imperfect, are generally associated with the uncertainty surrounding the likely benefits as well as the variability in benefits across time that the farmer expects to realize from adopting different SLM practices. Additionally, insecure tenure arrangements may pose an additional risk that the farmer who invests in SLM will not retain access long enough to reap a positive return on investment.

In general, household-level empirical studies provide evidence for the importance of investment, variable/maintenance, and opportunity costs, with fewer studies evaluating the importance of transaction and risk costs. As noted above however, very few household-level analyses produce monetary estimates of any of these costs. Project-level data, presented in Section 4, however, does provide at least some monetary estimates for investment and variable/maintenance costs, though with limited or no information on opportunity, transaction or risk costs. Nonetheless, estimates for investment and maintenance categories vary widely depending on the specifics of the situation, reflecting the large differences among regions, agro-ecological conditions, pre-project land uses, household asset endowments, and the differences in cost structure of the various types of activities considered. Thus, there are both pros and cons with each data source, and each on its own may be misleading. For instance, search and opportunity costs appear to be robustly important factors hindering adoption across a wide range of SLM practices, but these costs are not considered in project data. On the other hand, project data provides us with actual monetary outlays for at least two important cost categories, and so can give a better picture of the distribution of costs depending on SLM practice and local context.

3. Household-level agricultural practices and investments: adaptation and mitigation

There are a number of household agricultural practices and investments that can contribute to both climate change adaptation – a private benefit – and to mitigating greenhouse gases (GHGs)—a public good. For instance, a striking feature of many SLM practices and investments is that many of these activities also increase the amount of carbon sequestered in the soil or above ground, including agroforestry investments, reduced or zero tillage, use of cover crops, and various soil and water conservation structures. Thus, there are often long-term benefits to households from adopting such activities in terms of increasing yields and reducing variability of yields, making the system more resilient to changes in climate. Such activities generate both positive "local" (household-level and often community-level) net benefits as well as the global public good of reduced atmospheric carbon. However, adoption of many SLM practices has been very slow, particularly in food insecure and vulnerable regions in sub-Saharan Africa and Southeast Asia. There are a number of potential explanations for failure to adopt such activities, including:

(i) the fact that, though SLM activities increase productivity in the medium to long run through improved soil characteristics and water retention, in the short run, cultivation intensities and yields can decline (Giller et al. 2009), and yield variability can increase while farmers "learn by doing" (Graff Zivin and Lipper 2008). These factors reduce adoption incentives particularly where information is scarce, and where credit and insurance markets are thin or absent (Antle and Diagana 2003);

(ii) many activities generate local public goods (e.g. windbreaks, terracing and other water management structures), meaning that local collective action failures will lead to under-provision of such activities; and

(iii) tenure insecurity may reduce incentives to make long-term investments on the land (Place and Otsuka 2001). Additionally, public goods benefits generated through these activities are generally not compensated. The above explanations indicate that financing and risk management instruments, technical information to "smooth" the adoption process, collective action at the local level – ranging from village to watershed and landscape scales – and tenure security should all be key variables that explain adoption. In the following sections, we discuss in more detail the benefits and costs of various SLM activities and investments, as well as summarize factors associated with successful adoption found in the literature.

3.1 Agroforestry

Agroforestry generates adaptation benefits through its impact on reducing soil and water erosion, improving water management and in reducing crop output variability (Ajayi et al. 2009, 2007; Mercer 2004; Franzel and Scherr 2002). Trees and bushes may also yield products that can either be used for food consumption (fruits), fodder, fuel, building materials, firewood, or sold for cash, leading to greater average household income, and contributing to household risk management via reduced income variability (Ajayi et al. 2009; Franzel et al. 2004). Planting trees and bushes also increases carbon sequestered both above and below ground, thereby contributing to GHG mitigation (Verchot et al. 2007).

One of the key constraints to widespread adoption identified in the literature is the availability of a range of suitable tree and bush seedlings and seeds (Ajayi et al. 2003, 2007; Franzel et al. 2004; Phiri et al. 2004; Place et al. 2004; Place and Dewees 1999). Another key constraint concerns information and knowledge flows. Information on the types of agroforestry options, particularly those well-suited to local conditions, is often scarce; this lack of information increases the risk of planting expensive perennials that may not survive or otherwise do poorly (Ajayi et al. 2007; Franzel et al. 2004; Franzel and Scherr 2002). Thus, information available to farmers on the types of trees/bushes that are well-adapted to the locality is likely to be an important determinant of adoption. Information may come from a number of sources, including government extension programmes and NGO/donor programmes promoting the adoption of agroforestry. Note that since households are rarely “randomly” selected as participants in such programmes – and programmes may actively select certain households – researchers need to be able to account for both individuals’ decisions to “select” into the project, and for projects’ decisions to “select” individuals with certain characteristics. Another constraint concerns up-front financing costs and opportunity costs of land taken out of production when establishing trees and bushes, particularly where benefits are delayed (Ajayi et al., 2006; Mercer, 2004; Franzel 1999). Just how binding a cash constraint might be is obscured by the fact that many projects promoting trees/bush planting in fact provide the seeds/seedlings for free particularly in East and Southern Africa (Franzel et al., 2004). Nonetheless, a number of empirical studies find that wealthier households with greater landholdings are more likely to adopt agroforestry, indicating that cash constraints and opportunity costs of land in the near term are likely to affect adoption decisions (c.f. Phiri et al. 2004; Kuntashula et al. 2002; Place et al. 2004; Franzel 1999).

Additional factors constraining adoption include the labour and/or additional investments required to ensure that they receive sufficient water until roots are firmly established and that trees/bush seedlings survive (Blanco and Lal 2008; Franzel et al. 2004). In particular, local rules and norms regarding livestock grazing and bush-fires can substantially affect the costs of ensuring seedling survival. For instance, where customary practices allow free-grazing livestock post-harvest and the use of bush-fires to clear land, costs of protecting seedlings will be much higher than in communities that have functioning rules concerning grazing practices and limitations on bush-fires (Ajayi et al. 2006; Franzel et al. 2004; Phiri et al. 2004). Land tenure may also affect agroforestry investments; however, the relationship in this case may run in both directions; that is, greater tenure security may promote investments in agroforestry, but at the same time, investments in trees and bushes may lead to increased tenure security (Otsuka and Place 2001 and references cited therein).

Also, because many agroforestry investments yield benefits to both the investing farmer as well as farmers with surrounding fields, such investments will be underprovided where collective action is weak and/or very costly (Dutilly-Diane et al. 2003; McCarthy et al. 1999). In addition, providing agroforestry on communal grazing lands presents a “double” collective action problem (McCarthy et al. 1999) because incentives to under-provide tend to be even greater on communal lands that are also over-exploited. Communal grazing lands represent an important land use in many sub-Saharan African countries, and, though there remains some disagreement amongst rangeland ecologists as to drivers of degradation (Vetter, 2009; Ellis and Galvin, 1994), the fact remains that measures to restore degraded lands often include planting trees and bushes (Dutilly-Diane et al. 2007; Woomer et al. 2004).

To summarize, in terms of benefits, empirical evidence suggests that: where gains to farmers from reducing soil and water erosion are high (e.g. hillsides); where gains from water management are high (e.g. semi-arid and arid regions); and where climate variability is high, agroforestry options are more likely to be adopted. Also, agroforestry options that yield multiple benefits in the form of food, fodder and fuel are usually more attractive. In terms of costs, key cost constraints are summarized in Table 1 below.

Table 1. Key costs for agroforestry

Cost Category	Specific costs
Investment	Up-front financing
Variable/Maintenance	
Opportunity	Land, and labour during establishment
Transactions	Lack of seedlings in market-shed Access to Information on plant species and management Community rules on burning Collective Action costs • Negotiation • Monitoring and Enforcement
Risk	Risk of non-survival/poor performance Tenure Insecurity

3.2 Soil and water conservation

3.2.1 Conservation agriculture

Conservation agriculture (CA) incorporates a wide range of practices aimed at minimizing soil disturbance, and minimizing bare, uncovered soils (Blanco and Lal 2008, Chapter 8). The Food and Agriculture Organization of the United Nations (FAO) includes crop rotation as an essential component of conservation agriculture (http://www.fao.org/ag/ca/). Reduced or zero tillage plus incorporation of residues or other mulches reduces wind and soil erosion, increases water retention, and improves soil structure and aeration (Blanco and Lal 2008). Reduced erosion, improved soil structure, and greater water retention reduce yield variability due to weather events in general. Thus, conservation tillage practices can increase farm system resilience and improve the capacity of farmers to adapt to climate change. At the same time, such practices may reduce carbon losses that occur with ploughing, and also further sequester carbon via residue incorporation and reduced erosion (Lal 1987). However, in many circumstances, farmers who adopt such practices still periodically plough the land (Blanco and Lal 2008; Maguza et al. 2007). Whereas periodic ploughing may improve yields without compromising the gains in terms of resilience and adaptability, such ploughing will release stored carbon. However, there is little evidence on how much carbon would be released—as a fraction of the additional carbon stored during the period of zero tillage (Conant et al. 2007).

Following Blanco and Lal (2008), there are a wide range of practices that reduce soil disturbance in seedbed preparation vis-à-vis conventional tillage. “Conventional-tillage” is usually defined as animal or mechanical mouldboard ploughing. Conservation tillage practices include zero tillage, strip or zonal tillage, and ridge tillage. Zero tillage is as the name suggests; no mechanical preparation of the seedbed, except for narrow holes for seed placement (FAO 2008). A “zero-tillage system” generally presupposes that some residue will be incorporated into the plot. In strip or zonal tillage systems, the seedbed is divided between seeding zones that are prepared mechanically or by hand-hoe only where seeds will be planted, and zones that are not ploughed. The undisturbed portion should also be mulched. Finally the use of “planting pits”, where small holes are dug and seeds deposited, are often used in semi-arid areas prone to crusting, in order to retain moisture and build soil fertility (Imbraimo and Munguambe 2007; Roose et al. 1993). This practice also disturbs the soil less than conventional ploughing (Imbraimo and Munguambe 2007). In summary, as noted in FAO (2008), "minimum tillage" may take on different meanings in different contexts, which has led to some difficulty in comparing across different empirical assessments.

Incentives for individual farmers to undertake these practices will, of course, be a function of the marginal benefits of doing so. One of the key benefits affecting adoption of zero-tillage in many developed countries is the fact that fuel costs for tractors are significantly reduced. However, in the African context, very few farmers rely on fuel-based tractors or machinery to prepare the fields; Giller et al. (2009) point out that this may be a key reason behind limited adoption of such practices in sub-Saharan Africa *vis-a-vis* Latin America. Often, conservation tillage projects promote the use of specialized planting tools and other implements which are often not easily available in the area or are prohibitively expensive; this has been found to be a barrier to adoption in many African countries (Giller et al. 2009; Shetto and Owenya 2007 and the three case studies found therein; Boahen et al. 2007; Baudron et al. 2007; Bishop-Sambrook et al. 2004). Where herbicides are not accessible, increased labour required for weeding can also reduce the net benefits of zero tillage (Giller et al. 2009; Shetto and Owenya 2007 and the three case studies found therein; Boahen et al. 2007); though, as discussed below, cover crops and crop rotations can also be used to reduce weeds. Agro-ecological characteristics, such as soils and climate, can be important, though there is limited evidence in the empirical literature on which factors have consistent impacts on adoption. One key characteristic appears to be the drainage capacity of the soils; poorly drained soils may have relatively low benefits compared to well-drained soils at least in the short-medium term (up to five years) due to increased soil compaction in these early years, before the benefits to soil structure from zero tillage is realized (Blanco and Lal 2008). There is also some evidence that in the semi-arid regions where termites are abundant, surface mulch will be eaten by the termites (Sanginga and Woomer 2009, Chapter 10) limiting benefits to conservation agriculture. Generally, both private and public good benefits to CA should be greater on lands with more highly erodible soils and steeper slopes (Blanco and Lal 2010; Uri 1997).

Additionally, crop residues are used for a variety of purposes; as feed for livestock, as fuel for cooking, and as thatching/craft material. The greater these competing uses and the more costly are substitutes, the less likely will crop residues be left on the field. In many cases, it is long-standing customary practice to allow animals to graze fields post-harvest (Giller et al. 2009; Bishop-Sambrook et al. 2004; McCarthy 2004). While animals do not remove all of the residue, such grazing may leave too little residue to adequately cover the field, and grazing can be sufficiently heavy to compact the soil, making planting with zero-tillage more difficult (Bot and Benites 2005).

Finally, in many cases, the full benefits in terms of higher and more stable yields will not be realized for four years or more, whereas costs will be incurred up front (Blanco and Lal 2008; Hobbs et al. 2008; Bot and Benites 2001; Sorrenson 1997). Households with limited resources facing credit constraint will thus find it much more difficult to adopt conservation agriculture techniques, especially where initial investments are relatively high. Risks may also be greater initially where farmer's need to learn new practices and techniques and adapt them to on-farm conditions (Graff-Zivin and Lipper 2008). As with many agroforestry techniques, several proposed conservation agriculture systems require greater management skills than traditional systems, so farmers not only need to learn a new system but also a more sophisticated system (Sanginga and Woomer 2009; Bot and Benites 2001). Farmers' perceived risks of adopting conservation practices has been identified as a key constraint to adoption in the African context, and study results suggest the key role that can be played by extension (or other information sources) in reducing these risks (Bot and Benites 2001; Dreschel et al. 2008; Wondwossen Tsegaye et al. 2008). And, given the long-term nature of benefits accruing to these practices, security of tenure may also influence the adoption of such practices, to the extent that greater security increases incentives to invest for the long-run increases in yields and greater yield stability (Bot and Benites 2001; Steiner 1998); however, there is limited consistent empirical evidence on the tenure impacts *per se* (Mercer 2004).

To summarize, benefits in terms of greater yields and yield stability are more likely to be higher in sub-humid regions on soils with relatively good drainage, and where soil erosion is a significant problem, e.g. in hilly areas. Key costs are summarized in Table 2 below:

Table 2. Key costs for conservation agriculture

Cost Category	Specific costs
Investment	Machinery/Implement costs Availability of credit
Variable/Maintenance	Weed control costs, e.g. herbicides
Opportunity	Family labour for weeding Crop residues for animal feed/fuel
Transactions	Access to Information on conservation agriculture management Community rules on animal grazing post-harvest
Risk	Risk of poor yield performance Tenure Insecurity

3.2.2 Cropping patterns: cover crops, intercrops, improved fallows and alley crops

In addition to seedbed preparation, various cropping patterns can also serve to improve soil and water conservation characteristics; cover crops and rotation patterns can also alleviate potential weed problems where herbicides are not available or accessible to poor smallholders. Alley cropping between cover crops provides similar benefits to those described above for alley cropping with agroforestry systems; continuous cover between main crops can reduce erosion, build soil organic matter, and improve the water balance, leading to higher and more stable yields on the alleys sown to main crops (Blanco and Lal, 2008). Cover crops or improved fallows ensure that the soil is not left bare after harvest. Leaving residues on the field is one method of covering the soil, discussed above. Cover crops, on the other hand, are either additional crops planted on the field post-harvest or can also be crops inter-cropped with the main crop (usually the case where there is a single, relatively short rainy season, e.g. in the semi-arid regions of the Sahel) (Blanco and Lal 2008; Bot and Bonites 2001). Improved fallows generally mean the deliberate planting of fast-growing species – usually legumes – that produce easily decomposable biomass and replenish soil fertility (Matata et al. 2010; Sanchez 1999). The point is both to keep cropland covered during the entire year, and in the case of improved fallows, to increase soil fertility. With intercropping, the type of species and the timing of intercropping need to be carefully assessed in order to ensure minimum competition with the main crop (Bishop-Sambrook et al. 2004). An additional benefit from continuous crop cover is reduction in weeding and pest control, at least after some period; in fact many authors note that where adoption has been substantial, weed suppression has been perceived by farmers to be the main benefit (Tarawali 1999; Erenstein 1999). In terms of soil sequestration, cover crops and improved fallows can increase soil carbon particularly when combined with zero or minimum tillage (Govaerts et al. 2009; Bot and Bonites 2001; FAO 2001). In terms of adaptation, such practices can reduce erosion and enhance water retention, both of which should enhance resilience to drought (Conant 2009; Peterson and Westfall 2004). Additionally, land under cover crops can reduce soil surface temperature significantly, which may be beneficial particularly in drought years under high temperatures (Lal 1987).

A number of cover crops and improved fallow crops have had at least partial success in many African contexts. These include leguminous cover crops such as cowpea, pigeon pea, *lablab purpureus*, and *mucuna pruriens* (velvet bean) as well as improved fallows seeded with fast-growing tree species such as *sesbania sesbans* and *gliricidia sepium*. There are a number of factors associated with the successful adoption of cover crops and improved fallows, and many of these overlap with conservation tillage and residue practices noted above, particularly the ability to keep community animals from foraging on the land (Matata et al. 2010; Bishop-Sambrook et al. 2004; Ajayi et al. 2003). The availability of cover crop seeds has also been singled out as an important barrier to widespread and continued adoption (Morse and McNamara 2003; Tarawali et al. 1999; Steiner 1998).

Climate may also affect adoption both directly and indirectly. Woodfine (2009) discusses potential benefits (at least in the near term) of bare fallow versus improved fallow with a cover crop that arise due to relatively greater soil moisture storage in arid regions where biomass production of the cover crop is relatively low. However, Peterson and Westfall (2004) document increases from use of cover crops in income and food security in semi-arid regions. Additionally, improved fallows that generate sufficient biomass to both cover the ground and provide livestock feed are more likely to occur in higher rainfall areas leading to higher incentives to adopt in these areas (Steiner 1998). The longer the length of growing season, the more likely it is that cover crops can be seeded to minimize competition with staple food crops, and to spread labour requirements (Vissoh et al. 1998).

Population pressure and the need for continuous cultivation have also been found to increase adoption of cover crops (Vissoh et al. 1998; Ehui et al. 1989); however, other studies have found that high population pressures have instead led to abandonment of cover crops and severe land degradation (Cleaver and Schreiber 1992). And, where weed and pests problems are greater (e.g. invasive species such as *imperata cylindrica* and *striga h*. in West Africa), the higher should be the marginal benefits to cover crops (at least in later years), particularly where zero or minimum tillage is also practiced (Erenstein 1999; and case studies contained in Buckles et al. (eds.) 2000). As with conservation agriculture more generally, use of cover crops often requires access to specialized planting implements, since seeds will be planted directly into fields under the cover crop. Improved fallows that require land to be fallowed for two or more years to in order to provide soil fertility benefits are less likely to be successful where opportunity costs of land are high and farmer discount rates are high, as is often the case with poorer households with limited landholdings (c.f. Matata et al. 2010).

To summarize, agro-ecological conditions are likely to be very important in determining the benefits to cover crops and improved fallows; these include rainfall patterns, length of growing season and high average temperatures during key growth stages. Additionally, the presence of invasive species generally increases benefits from cover crops, but reduces the benefits of improved fallows. Benefits are also likely to be relatively higher in drought-prone areas, and on highly erodible soils. Key costs are summarized in Table 3 below:

Table 3. Key costs for cover crops and improved fallows

Cost Category	Specific costs
Investment	**Specialized planting implements**
Variable/Maintenance	
Opportunity	**Land, for improved fallows**
Transactions	**Availability of locally adapted seeds** **Access to Information on cover crop/improved fallow management** **Community rules on animal grazing post-harvest**
Risk	**Risk of reduced yields due to competition between cover and main crops, particularly in areas with short growing seasons**

3.2.3 Soil and water conservation structures/investments

There a number of fixed investments in structures for soil and water conservation, in addition to some of the agroforestry investments discussed above. For the farmer, these structures can provide benefits by reducing water erosion, improving water quality, and promoting the formation of natural terraces over time, all of which should lead to higher and less variable yields (Blanco and Lal 2008). Such structures also often provide benefits to neighbours and downstream water users by mitigating flooding, enhancing biodiversity, and reducing sedimentation of waterways (Blanco and Lal 2008). Structures include contour bunds – built of either earth or stone – to reduce runoff velocity and soil loss. Blanco and Lal (2008) note such bunds are appropriate for permeable soils on gentle to moderately sloping lands, may form the basis for terraces on steeply sloped land, and may reduce further gully erosion when built above and across gullies. However, Showers (2005) also shows that contour bunds can lead to significant increase in gully erosion on poorly drained soils subject to heavy rainfall events. Terraces also provide water conservation and reduced soil erosion benefits; Blanco and Lal (2008) state that these benefits will be greater when undertaken in conjunction with other structures such as grassed waterways and drainage channels both of which mitigate potential problems with waterlogging.

As with agroforestry, soil and water conservation structures often entail large up-front costs, with benefits accruing – sometimes slowly – over time. Additional costs include land taken out of production (Blanco and Lal 2008; Showers 2005), and in certain cases (e.g. stone bunds), both initial construction and annual maintenance can entail heavy labour requirements that may be especially costly to households with few prime-age adults.

Finally, it should be noted that there remains debate in the literature regarding the benefits of these options, particularly where design and construction of such structures does not take into account local conditions (Showers 2005). For instance, Dutilly-Diane et al. (2003) found that farmers in semi-arid northeastern Burkina Faso who had invested in stone bunds had lower yields in high rainfall years, due to water drainage problems. Because the Sahel had experienced drought conditions starting in the late 1960’s or early 1970’s, the focus had been on structures that retain water; however, as built, these structures lead to lower yields when high rainfall does occur. Herwig and Ludi (1999) found similar disadvantages to waterlogging in sub-humid regions of Ethiopia and Eritrea; these authors also found that, despite significant reductions in soil erosion and runoff, yields were not significantly higher. In recent years, a number of researchers have pointed out the largely failed attempts at promoting soil and water conservation in sub-Saharan Africa (and elsewhere); these authors claim that for such measures to be successful, they must be designed, adapted and tested in conjunction with local farmers (Showers 2005; Hincliffe et al. 2005). Hincliffe et al. (2005) claim that there are very few projects where these structures are maintained after the project is over; information on previous soil and water conservation projects would be particularly important to actually empirically verify this assertion. Additionally, these authors argue that few generalizations can be made to “scale-up” these measures without fairly intensive – and expensive – participatory research programmes at a very local level. Nonetheless, there remains a dearth of empirical evidence.

To summarize, soil and water conservation structures are more likely to produce relatively high benefits in mountainous areas where farming occurs on the slopes, where benefits to water retention are relatively great (e.g. more arid lands), and potentially where gully and rill problems have already surfaced. Such structures will yield lower net benefits, and perhaps lead to greater yield variability, where potential waterlogging problems cannot be managed at reasonable costs. The latter indicates that incidence of extreme high rainfall events may reduce incentives to invest in structures that nonetheless increase water retention in dry years. Key costs for soil and water conservation structures are given in Table 4.

Table 4. Key costs for soil and water conservation structures

Cost Category	Specific costs
Investment	High up-front financing costs High up-front labour costs for construction
Variable/Maintenance	Maintenance materials
Opportunity	Household labour, for construction and maintenance Land, where structures take some land out of production
Transactions	Access to information and evidence on benefits to such structures, and suitability for local environment Collective Action costs, where high benefits could be realized from coordinated or collective action
Risk	Risk of reduced yields, particularly in high rainfall years where structures mainly built to conserve water Tenure Insecurity

3.3 Grazing land management

The vast majority of agricultural land in sub-Saharan Africa (and indeed, the world) is in rangelands. Rangelands include grasslands, bush, and woodland, and can include croplands where these are grazed after harvest (Homewood 2004). Rangeland is particularly important in the arid and semi-arid regions, and there is a (rough) estimate of 12.8 million km^2 in sub-Saharan Africa (Le Houerou 2006), of an estimated arable area 23.8 million km^2 (Nachtergaele 2000). Over 6 million km^2 are in hyper-arid regions, some of which are still periodically used for grazing and/or cultivation (Nachtergaele, 2000). Also, about half of the arable area is in forested land, and about 2 million km^2 is in protected areas, meaning that grazing land area is far greater than actual land used, which was estimated at just 1.5 million km^2 in 1998 (Nachtergael, 2000). In terms of mitigation, many studies have suggested rangelands could be a significant source of carbon sinks, mainly due to the large land area covered as opposed to amount that could be sequestered per unit area (Lipper et al. 2010; Smith et al. 2007; Conant and Paustian 2002; Lal 2002). In fact, the fourth IPCC assessment reports that "grazing land management" has the second highest technical potential to mitigate carbon (Smith et al. 2007). More interestingly, the widely-cited McKinsey report not only provides very large potential sequestration estimates, but also reports *negative* net costs of achieving those benefits, where net costs are calculated over a 20-year time horizon.

The number one reason given for increased carbon emissions and loss of soil carbon sequestered on degraded rangelands is overgrazing, and so eliminating or moderating grazing intensities is proposed to increase carbon sequestered on these rangelands (Batjes 2004; Conant and Paustian 2002; Nachtergaele 2000). However, another line of researchers claim that grazing intensities have limited impact on rangeland vegetation and productivity; this claim is generally associated with the "non-equilibrium theory" of rangeland dynamics school of thought[2] (c.f. Niamir-Fuller 1999, Chapter 9). Even within that school, it has been recognized that grazing densities could affect replenishment of seed banks when it occurs during critical phases of the growing cycle, e.g. before the grasses/forages seed (c.f. Hiernaux 1993). More recent work trying to tease out the effects of grazing intensities from rainfall events on vegetation productivity indicate that both are important, particularly in the semi-arid and sub-humid environments (Vetter 2009; Wessels 2007; Vetter 2005). On the one hand, in the arid and hyper-arid regions, grazing intensities might simply never be high enough to cause much damage, so that climate would be the key driving factor, as posited by the "non-equilibrium" school. On the other hand, Derner

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[2] According to the non-equilibrium theory, livestock grazing has a limited effect on long-term vegetation productivity of semi-arid and arid rangelands, which is instead largely determined by rainfall.

and Schuman (2007) find that increased carbon sequestration results from reduced stocking densities only in the semi-arid regions (<440-600mm). Taken together, these results suggest that sequestration benefits from reduced grazing are likely to be greatest where rainfall ranges between 150 and 440mm. One possible reason for the hard-to-interpret results may be because the response of the rangeland to decreased grazing intensity may also be a function of past grazing history as well as underlying agro-ecological conditions (Shrestha et al. 2005; Tennikeit and Wilkes 2008; Smith et al. 2008). Additionally, many rangeland rehabilitation programmes are aimed at reducing encroachment of invasive species, mainly non-edible bushes, which are also often seen as a sign of overgrazing. Removing these, often through burning, can lead to increased emissions in the short term, as well as lower carbon sequestration where these inedible bushes are not replaced with edible vegetation. In general, then, there remains a great deal of uncertainty over where and whether reduced grazing intensities reduce emissions and/or increase carbon sequestered, unless such measures are coupled with other activities to increase "good" plant biomass, reduced erosion and reforestation, as detailed in Woomer et al. 2004.

In terms of adaptation, grazing land management benefits are similar to those for cropland management; better soil quality and structure and better water management improves the capacity of rangelands to continue supporting livestock even under extreme weather events. Moderate grazing intensities may lead to reduced variability in overall livestock production, and increase the ability of herds to "bounce-back" after drought, though there is little long-term data to support that hypotheses (though c.f. Ellis 1997; McCarthy 1999). In addition to moderating grazing intensities, rangeland improvements include many of the activities listed above under agroforestry (silvopastoralism) and soil and water conservation structures that lead to both increased carbon sequestration as well as increased resilience.

In terms of cost, the first issue that arises is that costs will be borne immediately, while benefits will not be realized until some future time. Credit constraints will again be important. Restoration practices that require excluding livestock for some period of time are likely to be very expensive, and very difficult to enforce (Lipper et al. 2010; Dutilly-Diane et al. 2007; Badini et al. 2007). In essence, the choice between "working lands" restoration projects and changing land use (to exclude all livestock) will be a function of the trade-offs between maintaining livelihoods currently, the discount rate and risk preferences, and the rate of increase in productivity from exclusion (Zilberman et al. 2007; Wu et al. 2001). In the Sahelian context, Le Houerou (2006) argues that controlled access and limiting grazing intensities may produce better results, though such management plans will likely entail greater costs of enforcement (Lipper et al. 2010).

Unlike agroforestry and investments in soil and water conservation structures that can provide both private and public benefits (when undertaken on both private and public land), controlling grazing intensities reduces a negative externality from use of communal grazing lands; and these lands characterize much of rangelands in sub-Saharan Africa. Incentives to provide a public good (non-rivalrous, non-excludable) are often qualitatively different from incentives to reduce a negative externality arising from shared use of a communal resource (rivalrous, non-excludable) (c.f. Dasgupta and Heal 1979; Cornes and Sandler 1986), and are likely to require a greater degree of collective cohesiveness. Thus, the capacity to engage in collective action required to manage grazing land is likely to be higher than that for both private and collective investments in agroforestry and soil and water conservation structures.

Additionally, use of communal pastures in many sub-Saharan African countries often includes the rights of transhumants to use these pastures; and by the same token, community members can often migrate to other grazing lands (McCarthy 2004; Niamir-Fuller (ed) 1999). Pressure on local grazing land is thus also a function of both others' rights to access these lands as well as community members' capacity to move to access non-community resources. Enclosures and grazing restriction rules may pose even greater costs of establishment and enforcement when traditional users include not only locals, but non-locals as well.

At the community level, poorly managed communal grazing land may lead to encroachment by those who wish to cultivate crops. Results in McCarthy (2004) show that encroachment as a response to poorly managed communal grazing land can be significant. As noted above, switching land use from grazing land to crops often leads to carbon emissions. Also, to the extent that well managed pastures are more resilient to extreme weather events than are crops, failures in collective management will also lead to reduced adaptive capacity (Goodhue and McCarthy 2009; Niamir-Fuller (ed) 1999). Finally, we can raise the issue of property rights so prominent in the climate change as well as other strands of literature. As noted above, in systems where livestock owners move in response to different weather events as well as other transactions costs, more flexible access rights enable livestock owners to make the best use of available resources (Sandford 1982; Coppock 1994; Niamir-Fuller, 1999). The ability to "weather" weather shocks, where the main input is mobile, will depend on access rights to various resources. Here, ambiguous, ill-defined rights may well help livestock owners to absorb weather (and other) shocks (Goodhue and McCarthy 2009; McCarthy and Di Gregorio 2007). But, the trade-offs include both overgrazing in "good" times, and under-provision of public goods such as agroforestry and soil and water conservation investments as well as management of invasive species. Insurance values are likely to dominate where climate events are more variable both in temporal and spatial scales; negative impacts from overgrazing and under-provision of investments are more likely to dominate where population pressures are high and heterogeneity amongst users is high (McCarthy et al. 1999; Turner 1999).

To summarize, increasing carbon and resilience of grazing lands in Africa is likely to entail the need for collective action, not only amongst community members but also by others with secondary or tertiary rights of access. Benefits are only likely to be realized with both reduced grazing intensity (mitigating the "tragedy of the commons") and increased investments on communal grazing lands (provision of public goods). The literature is rather divided on exactly where benefits to livestock owners are likely to be higher in terms of pasture productivity and resilience, though these are likely to be relatively higher in the semi-arid regions on highly erodible soils. Table 5 presents the key costs for grazing land management.

Table 5. Key Costs for Grazing Land Management

Cost Category	Specific costs
Investment	High up-front financing costs for conservation structures High up-front labour costs for construction
Variable/Maintenance	Maintenance materials
Opportunity	Land, particularly where grazing exclusions are pursued for a number of years
Transactions	Access to information and evidence on benefits for SLM on grazing lands Collective Action costs, both for realizing public investments on common grazing lands and in reducing negative externalities Managing access by those with secondary and tertiary access rights
Risk	Fewer options to exercise livestock mobility in response to climate variables, where grazing exclusions or restrictions adopted Tenure Insecurity Uncertain gains in productivity from exclusions and restrictions

4. Project-based evidence on cost barriers to climate smart sustainable land management adoption

In this section, we review empirical evidence on investment and maintenance costs from agroforestry, soil and water conservation, and grazing land projects. As noted in the previous section, agroforestry systems have great potential to diversify food and income sources, improve land productivity and stop and reverse land degradation, but their establishment can be quite costly, with high labour costs for land preparation (which vary according to slope and/or depending on the system used to protect natural regeneration) and planting as well as input costs for purchasing tree seedlings, cuttings or nursery plants and fertilizers. On the other hand, maintenance costs are relatively low (Liniger et al. 2011).

Conservation Agriculture (CA) often requires substantial initial investments but the range of costs can be very wide, depending on the investment type: from zero (e.g. if the hand-based planting method is adopted) to very high (e.g. buying a special no-till drill to simultaneously seed and fertilize annual crops). In certain cases, agronomic measures have negligible establishment costs (e.g. green manuring or compost production) but can involve opportunity costs. For example, systems that require terracing generally incur high labour costs for the construction of terraces (which vary depending on the slope and the number of barriers needed, the distance to the material and the level of mechanization). They can also involve opportunity costs associated with loss of planted area. The construction of vegetative strips requires less working days and can provide a cost-saving alternative to terracing. Establishing water harvesting structures may be costly but these technologies are often easy to maintain and represent a common practice worldwide. Soil and water conservation structures require relatively high up-front costs in terms of labour and/or purchased inputs (Amsalu and de Graaf 2007; Mati 2005; Liniger et al. 2011).

Grazing land improvement is often based on enclosures and planting of improved grass and fodder trees to enhance fodder and consequently livestock production. After initial significant one-off investment costs, maintenance costs decrease substantially as the grass cover closes up and maintenance activities such as replanting are reduced or cease (Wocat 2007; Liniger 2011). However, as discussed in previous sections, the opportunity costs can be quite significant.

Table 6 presents some examples of project-level estimates of up-front establishment and maintenance costs associated with the adoption of SLM practices. The data in the table are taken from different sources and thus there is variation in the method of cost calculation, implying that comparison between them is not possible. However, some striking conclusions can be drawn in any case. Perhaps most striking is that maintenance costs can be quite high for a number of these practices, which indicates that it is indeed important to verify significant returns from such systems to ensure viability. In contrast, there are several activities that have relatively low establishment costs, indicating that financing to overcome this barrier at a larger scale could actually be feasible even within existing resource pools.

Table 6. Examples of investment and maintenance costs of SLM options

Technology options	Practices	Case study	Establishment costs	Average maintenance costs
			US$/ha	US$/ha/year
Agro-forestry	Various agro-forestry practices	Grevillea agroforestry system, Kenya	160	90
		Shelterbelts, Togo	376	162
		Different agroforestry systmes in Sumatra, Indonesia	1,159	80
		Intensive agroforestry system (high input, grass barriers, contour ridging), Colombia	1,285	145
Soil and water conservation	Conservation agriculture (CA)	Small-scale conservation tillage, Kenya	0	93
		Minimum tillage and direct planting, Ghana	220	212
		Medium-scale no-till technology for wheat and barley farming, Morocco	600	400
	Improved agronomic practices	Natural vegetative strips, The Philippines	84	36
		Grassed Fanya juu terraces, Kenya	380	30
		Konso bench terrace, Ethiopia	2,060	540
	Integrated nutrient management	Compost production and application, Burkina Faso	12	30
		Tassa planting pits, Niger	160	33
		Runoff and floodwater farming, Ethiopia	383	814
Improved pasture and grazing management	Improved pasture management	Grassland restoration and conservation, Qinghai province, China (1)	65	12
	Improved grazing management	Rotational grazing, South Africa	105	27
		Grazing land improvement, Ethiopia	1,052	126

Sources: Wocat 2007, Liniger et al. 2011, FAO 2009, Cacho et al. 2003

However, once we look into opportunity costs, the picture changes somewhat, although the relative dearth of information on opportunity costs confines this analysis to a few examples. Cacho et al. (2003) computes the opportunity costs of implementing different agroforestry systems (rubber, cinnamon, dammar, oil palm) that are common on the island of Sumatra (Indonesia). Opportunity costs are estimated using the Net Present Value (NPV) of switching land use from cassava to agroforestry on degraded land. Results show that such costs are positive for dammar, oil palm and rubber (ranging between US$72.46 and US$132.35/ha) and negative for cinnamon (US$-78.99/ha). Only the cinnamon agroforestry system is profitable in the short as well as long run. All other systems are profitable only in the long run.

The length of the loss period depends of course on various factors, including the profitability of the alternative practice with respect to the conventional management, agro-ecological and soil fertility conditions. It also depends on the size of the farm or enterprise involved. For example, in the same study on agroforestry systems in Indonesia, Cacho et al. (2003) found that with agroforestry adoption on more productive land all systems are attractive at a real discount rate of 15 per cent (with NPVs ranging from US$173 to US$1,621/ha and with oil palm providing the highest profit, followed by dammar agro forestry). However, the number of years required for smallholders to obtain a positive cash flow ranges between five and 15 years, indicating a much larger opportunity cost burden than for large enterprises (income loss of switching from previous systems to agroforestry).

Data on improved grazing management from Qinghai China (reduced stocking and improved winter feeding) also indicates the variation in opportunity costs by herd size, as shown in Table 7.

Table 7. Example of opportunity costs of implementing improved grazing management practices

Size of herd	Baseline net income	NPV/HA over 20 years	No years to positive cash flow	No of years to positive incremental net income compared to baseline net income
	($/ha/yr)	($/ha)	(number of years)	(number of years)
Small	14.42	118	5	10
Medium	25.21	191	1	4
Large	25.45	215	1	1

Source: Wilkes 2011

Although implementing improved grazing management practices is found to be profitable for all households over a 20-year time frame (NPV calculated at 12 percent is always positive), households with small herds are found to bear higher opportunity costs than households with medium and large herds. In fact, the number of years needed to obtain positive incremental net income compared to baseline net income goes from one year (large herd size) to ten years (small herd size).

5. Concluding observations

While there have been a number of factors identified which hinder adoption of SLM techniques yielding both climate change adaptation and mitigation benefits, a few stand out for all techniques. Firstly, since the point of most of these techniques is to improve soil quality (structure, fertility, water regulation), the benefits are often not appreciable for at least five years, yet costs are borne immediately. These costs include opportunity costs of labour and land, as well as up-front cash outlays that many poor farmers simply cannot afford given thin credit markets, and limited results available suggest they are the group facing the highest opportunity costs. Secondly, there is often limited information available about alternative techniques as well as limited local experience with such practices that hinders adoption. This increases uncertainty and risks associated with adoption, exacerbated by the fact that insurance markets are even more thin – or non-existent – than credit markets. Thirdly, even where farmers might invest in certain techniques, inputs are often not available in local markets. Fourthly, community norms and rules regarding livestock and bush fires often make it much more costly to employ such techniques. And finally, communal forests and pastures require collective action both to provide public goods (e.g. agroforestry and investments in soil and water conservation) and to reduce negative externalities from overuse (overstocking, deforestation). When costs of collective action are high, both under-provision of public goods and overuse will result.

In other cases, factors affecting adoption rates are more specific to the technique. For conservation agriculture programmes that promote use of crop residues, the opportunity costs of those residues is an important determinant of adoption. The costs of managing weeds is also important, and depends on the availability and costs of herbicides, the opportunity costs of labour, and/or the efficacy of cover crops in reducing the weed problem. The net benefits of certain soil and water conservation structures in specific environments are difficult to assess generally, and these benefits are often simply not known with any precision at local levels. Net benefits to different grazing management schemes will also differ depending on land use history, underlying agro-ecological characteristics, and the opportunity costs of taking lands out of production.

The bottom line is that promoting various SLM techniques is going to be more costly than some of the figures currently being bandied about in the climate change literature Indications are that these costs are likely to be higher for the poorest producers, who are perhaps the most important to reach given the high rates of food insecurity they bear, as well as exposure to adverse effects of climate change and highly limited capacity to respond. For those who have been looking at adoption of SLM techniques, this will come as no surprise. On the other hand, the agriculture sector was neglected for many years, but is now back on the “development agenda”. The hope is that climate change adaptation and mitigation funds can be leveraged with agriculture-sector specific funds to develop “climate-smart” agriculture development strategies based on realistic assumptions about their costs and benefits, bearing in mind the empirical lessons learned discussed in this paper.

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There are a wide range of agriculture-based practices and technologies that have the potential to increase food production and the adaptive capacity of the food production system, as well as reduce emissions or enhance carbon storage in agricultural soils and biomass. However, even where such synergies exist, capturing them may entail significant costs, particularly for smallholders in the short-term. In this paper, we provide a brief review of the adaptation and mitigation benefits from various practices, and then focus in detail on empirical evidence concerning costs and barriers to adoption, both from household and project-level data. Findings indicate that up-front investment costs can be a significant barrier to adoption for certain investments and practices, and furthermore, the evidence also supports the hypotheses that opportunity and transactions costs across a wide range of investments and practices. Additionally, potential synergies between food security, adaptation and mitigation opportunities, as well as costs, can differ substantially across different agro-ecological zones, climate regimes, and historical land use patterns.

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