Climate-Smart Agriculture

Enhancing Resilient Agricultural Systems, Landscapes, and Livelihoods in Ethiopia and Beyond

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7. Restoring Degraded Landscapes for Improved Ecosystem Services

Wolde Mekuria*

Summary

There is a consensus that major improvement in agricultural systems is necessary to meet the food demand of the growing global population. Restoring degraded lands could play multiple roles in meeting the growing demand for food, ensuring food security, improving rural livelihoods, and adapting to and mitigating the effects of climate change. Restoration of degraded landscapes, which is one of the climate-smart approaches, is critical for conserving water, increasing yields, sequestering carbon, and reducing risks in rainfed agriculture through improving water availability and reducing soil erosion. Restoration of degraded landscapes can generate both private and public benefits, and thus constitutes a potentially important means for generating "win-win" options. In connection with the aforementioned, case studies from the highlands of Tigray, northern Ethiopia, have demonstrated that exclosures are effective for restoring degraded landscapes, thereby improving provisioning, regulating, supporting, and cultural ecosystem services. Upon protecting communal grazing lands via exclosures, the soil carbon, total soil N, and available P contents increased from 29 (±4.9) to 61 (±6.7) Mg C ha^{-1}, 2.4 (±0.6) to 6.9 (±1.8) Mg ha^{-1}, and 17 (±3) to 39 (±7) Kg ha^{-1}, respectively. The case studies also indicated that exclosures are important in reducing soil erosion (47% decrease following establishing exclosures), sustaining perennial habitat, restoring vegetation composition, and improving indigenous plant species diversity and richness. Further, over a period of 30 years, the NPV of the exclosure ecosystem services under consideration was about 28% (USD 837), which is higher than alternative wheat production, justifying that exclosures have economic and livelihood benefits. Restoration of degraded landscapes is, thus, essential for achieving improved, resilient, and sustainable production systems, livelihoods, and ecosystems.

Keywords: ecosystem, exclosure, landscape restoration, resilience, sustainability

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7.1 Introduction

According to the Food and Agriculture Organization of the United Nations (Branca et al. 2011), close to one billion people went hungry in 2010. When the global population reaches 9 billion by 2050, food needs are projected to increase by 70% (World Bank 2010). In contrast, climate change is projected to reduce global average yields (World Bank 2010, Zhao et al. 2017). For instance, Zhao et al. (2017) indicated that each degree Celsius increase in global mean temperature is estimated to reduce average global yields of wheat by 6%. This same study indicated that rice yields would cut by 3.2%, and maize by 7.4% for each degree of Celsius warming. Indeed, in 2011 the Horn of Africa was hit by the worst drought in 60 years and was consequently plagued by hunger (Branca et al. 2011).

Climate change is also adding pressure to the already stressed ecosystems of smallholder farms (Grainger-Jones 2012). Studies (Cline 2007, World Bank 2010) predict that without strong adaptation measures, severe crop yield reductions can be expected in the coming decades, particularly in Sub-Saharan Africa and South Asia, where farming systems are highly sensitive to climate change or variability although rural households are highly dependent on agriculture. An assessment by Cline (2007), based on a pessimistic assumption about global warming, estimated a decline in worldwide agricultural productivity by 3% to 16% by the 2080s; this loss could be even worse in Africa, i.e., 17% to 28% (Cline 2007). Therefore, there is a consensus that major changes in agricultural systems will be required to meet the food demand of an increasing global population under a changing climatic condition (Branca et al. 2011, Grainger-Jones 2012).

Over the past 45 years, about 1.2 billion hectares (11% of the Earth's vegetated surface) have been degraded by human activity (Grainger-Jones 2012). In developing countries alone, an estimated 5 million to 12 million hectares of land become infertile for use in agriculture due to severe degradation (Scherr 1999 cited in Grainger-Jones 2012). The Global Partnership on Forest Landscape Restoration estimates that there are over 700 million hectares of degraded forest landscapes in Africa, which offer opportunities for restoring or enhancing the functionality of "mosaic" landscapes that mix forestry, agriculture, and other land uses (Minnemeyer et al. 2011). Sub-Saharan Africa is one of the regions worst affected by land degradation, where per-capita food production continues to decline, and hunger affects about a third of the region's population (Scherr 1999 cited in Grainger-Jones 2012). The continued cultivation of marginal areas (without adequate management), deforestation, wind and water erosion, and overgrazing, are all major drivers of widespread land degradation.

Degraded landscapes such as communal grazing lands, woodlands, and agricultural lands can be restored to provide ecological connectivity for improved water and nutrient flows, as well as improved habitat conditions for indigenous tree species (World Bank 2010, Mekuria and Veldkamp 2012). As climate change intensifies, nutrient flow and hydrological resources improvements become increasingly important as adaptation strategies (Millar et al. 2007). Along these lines, the climate-smart agriculture-landscape restoration approach could provide options for meeting the growing food demand while providing climate change adaptation and mitigation benefits, as it simultaneously improves food availability and rural livelihoods, as well as restores degraded landscapes (World Bank 2010, Scherr et al. 2012).

The landscape restoration approach, which aims to restore degraded ecosystems, has played an important role in mitigating human pressure on natural ecosystems (Holl et al. 2003), improving ecosystem services (Doren et al. 2009, Scherr and Sthapit 2009, Bullock et al. 2011), reversing biodiversity losses (Bullock et al. 2011, Bernazzani et al. 2012), and improving agricultural productivity and food security (Mekuria et al. 2009, Milder et al. 2011). The restoration of degraded ecosystems can also generate both private and public benefits and, thus, may constitute a potentially important means of providing "win-win" options for addressing poverty, food insecurity, and environmental problems (Scherr et al. 2012).

In Ethiopia, land resources are facing severe degradation. This is largely a consequence of deforestation, over-cultivation, and overgrazing, which together result in significant environmental degradation and reductions in provisioning, regulating, supporting, and cultural services derived from ecosystems (Mekuria et al. 2015). For example, the rate of deforestation in the Ethiopian highlands was estimated at 160,000–200,000 ha yr^{-1} (Bishaw 2001), the average rate of soil erosion for all kind of land use was estimated at 35 Mg ha^{-1} yr^{-1} (Keyser and Sonneveld 2001), and nutrient depletion was reported as 30 kg ha^{-1} yr^{-1} of nitrogen and 15–20 kg ha^{-1} yr^{-1} of phosphorous (UNDP 2002). Consequently, the restoration of degraded watersheds through the establishment of exclosures has become increasingly important in the highlands of Ethiopia (Mekuria et al. 2011b). Exclosures (Figure 7.1) are common land areas, which are traditionally "open access," where wood cutting, grazing, and other agricultural activities are forbidden or strictly limited as a means to promote the restoration and natural regeneration of degraded lands (Mekuria et al. 2011a,b).

This chapter briefly discusses (1) the effects of exclosures on restoring degraded landscapes and improving ecosystem services; (2) the importance of the restoration of degraded landscapes for achieving improved, resilient, and sustainable production systems, livelihoods, and ecosystem health; and (3) the impacts of exclosures on the livelihoods of smallholder farmers.

7.2 Methods

7.2.1 Study area

This chapter presents the results of five case studies on the changes in ecosystem carbon stock, vegetation composition, soil erosion, soil properties, and income and livelihoods following the establishment of exclosures. The studies were conducted in the highlands of Tigray at lat. 12°–15° N, long. 36°30′–40°30′ E, northern Ethiopia. The altitude of the study sites ranged from 2,232 to 2,937 m above sea level. The exclosures in the study area were established three to four decades ago. All of the sites had semiarid climate conditions. From 2000 to 2006, the mean annual rainfall varied between 578 and 671 mm yr^{-1}, with an average of 609 mm yr^{-1} (Ethiopian Meteorological Service Agency 2007). The rainy season usually starts at the end of June and ends in September. The growing season stretches from 90 to 120 days. The mean minimum temperature ranges from 7.8 to 11.6°C, and the mean maximum temperature ranges from 22.2° to 28.2°C (Ethiopian Meteorological Service Agency 2007). Landscape composition in the study districts where exclosures were located

Figure 7.1 Examples of exclosures at ages (a) 5 years, (b) 15 years, and (c) 20 years, established on communal grazing lands in the Douga-Tembien District, Tigray, in northern Ethiopia (photos by Wolde Mekuria).

includes cultivated lands (9%–33%), forest lands (3%–58%), exclosures (3%–16%), communal grazing lands (6%–39%), and other uses (20%–41%). Mixed crop-livestock farming is the backbone of household livelihoods in all of the study sites. The major cultivated crops include barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), tef (*Eragrostis tef* [Zucc.] Trotter), common bean (*Phaseolus vulgaris* L.), and sorghum (*Sorghum bicolor* [L.] Moench). Soils of the study sites are classified into four major groups: Luvisols (Alfisols), Regosols (Entisols), Cambisols (Inceptisols), and Calcisols (Aridisols) (Soil Survey Staff 1996, IUSS Working Group WRB 2006).

7.2.2 Exclosure management

Three to four decades ago, in an effort to restore degraded landscapes and improve the services that they provide, communities in the northern highlands of Ethiopia embarked on exclosure schemes to protect and regenerate degraded communal grazing lands (Mekuria et al. 2011b). Exclosures are usually established in steep, eroded, and degraded areas that have been used for grazing, wood collection, and other purposes in the past. Priority areas for establishing exclosures are normally identified through a joint committee, which is composed of local communities and governmental and non-governmental organizations (Descheemaeker et al. 2006, Mekuria et al. 2011b). Final decisions are made at a general meeting of the community (Yami et al. 2013). Exclosure management and protection have proven to be an effective sustainable landscape management option because these lands are owned and managed by the local community (Descheemaeker et al. 2006). The coverage of a given exclosure ranges from 1 ha to 700 ha (Nedessa et al. 2005).

7.2.3 Data collection and analysis

A space-for-time substitution approach (Mekuria et al. 2011b) was used to detect changes in ecosystem services following the establishment of exclosures with ages of 5, 10, 15, and 20 years. In five separate studies undertaken, changes in regulating (e.g., carbon sequestration and soil erosion control) and supporting ecosystem services (e.g., soil fertility improvement and vegetation restoration), economic viability, and the perception of local communities following the establishment of exclosures on communal grazing lands were investigated (Mekuria et al. 2009, Mekuria et al. 2011ab, Mekuria and Veldkamp 2012, Mekuria and Aynekulu 2013). Exclosures with ages of 5, 10, 15, and 20 years were selected and replicated three times, and each exclosure was paired with a plot of adjacent grazing land during statistical analysis.

To investigate the changes in vegetation composition, richness, and diversity, vegetation inventory was undertaken with the method used by Mekuria and Veldkamap (2012). To investigate the changes in soil properties and nutrient contents, soil samples were collected and analyzed (Mekuria and Aynekulu 2013). Dominant woody species were identified based on relative importance values (i.e., the sum of relative basal area, relative frequency, and relative density) (Mekuria et al. 2011b). The methods of Hoff et al. (2002) and Snowdon et al. (2002) were used for measuring the aboveground biomasses of the dominant woody species. Selected individual plant species in exclosures and the communal grazing lands were harvested and weighed. Measured fresh biomass of the aboveground vegetation was adjusted to dry biomass using a correcting factor after oven drying at 65°C for 72-78 hours until a constant weight was attained. Carbon fractions in the aboveground biomass were estimated by multiplying the oven-dried biomass by a factor of 0.5 (Snowdon et al. 2002).

The enhancement of aboveground carbon is considered to be an indirect benefit of exclosures on communal grazing land. The necessary input factors are land and labor. As certified emission reductions (CER) are traded as CO_2 units (UNFCCC 2003), carbon storage in this study was converted into CO_2-e quantities (Mg CO_2 ha^{-1}) by multiplying the carbon storage (Mg C ha^{-1}) by a molar conversion factor of 3.67 (Olschewski and Benitez 2005). Additionally, for determining the carbon revenues, permanent carbon prices were transformed into prices for temporary credits, in accordance with Olschewski et al. (2005) and Mekuria et al. (2011a). Assuming a tCER (temporary certified emission reduction) expiring time of 5 years, an average price of USD 25 per permanent credit, and a discount rate for Annex I countries of 3% results in a price of USD 3.43 per temporary certified emission reduction (Mekuria et al. 2011a). Labor cost for the guards protecting the exclosures was calculated as a wage per hectare, which is based on a guard's monthly salary and the coverage of the exclosure to which they are assigned. Costs and benefits analysis was conducted based on market prices for valuing the project impacts. Given the long-term project horizon, costs and benefits occurring at different points in time were discounted to make them comparable. Net present value (NPV) was used as a decision criterion and was calculated using the equation described in Mekuria et al. (2015).

Using a revised universal soil loss equation (RUSLE), Mekuria et al. (2009) investigated the effectiveness of exclosures in combating soil erosion. The RUSLE was used to estimate potential soil losses. In addition, data on local community perceptions on exclosures was obtained from a survey of 62 farm households and five local experts. In-depth interviews, group discussions, and non-participant field observations were also carried out to obtain additional information.

7.3 Major Highlights

Restoration of degraded landscapes is important for achieving improved, resilient and sustainable production systems, livelihoods, and ecosystems. This case study has demonstrated that exclosures provided higher levels of ecosystem services than did non-closed lands. Differences in ecosystem carbon stock (ECS), total soil N stock and available P stock between exclosures and grazing lands varied between 29 (±4.9) and 61 (±6.7) Mg C ha^{-1}, 2.4 (±0.6) and 6.9 (±1.8) Mg ha^{-1}, and 17 (±3) and 39 (±7) Kg ha^{-1}, respectively. All differences in ecosystem services increased with exclosure duration. Differences in plant species richness and biomass between exclosures and communal grazing lands were higher than differences between older and younger exclosures. Over a period of 30 years, sequestered carbon dioxide was 246 Mg ha^{-1}, total soil nitrogen increased by 7.9 Mg ha^{-1}, and additional available phosphorous stocks amounted to 40 kg ha^{-1}. The NPV of the exclosure ecosystem services under consideration was about 28% (USD 837), which is higher than for alternative wheat production, demonstrating that exclosures have a comparative advantage to alternative agricultural practices. Given that more than 75% of the respondents had a positive view on exclosure effectiveness for restoring degraded landscapes, there are substantial opportunities to mobilize local communities in an effort to establish more exclosures. Establishing exclosures on communal grazing lands can be effective for restoring degraded landscapes and thereby increasing the services that they provide.

The estimated soil loss from the free grazing lands was higher than soil loss in exclosures by 47%, which indicates that exclosures are effective for controlling soil erosion. The RUSLE results agreed with the opinions of the majority of respondents, 67% of whom said that soil erosion in the study area was severe and affected the quality of residents' lives. The majority of respondents (70%) also rated the effectiveness of exclosures in controlling soil erosion as "high". Local communities were optimistic that the remaining degraded lands could be rehabilitated and converted to productive land through exclosure land management. The local community's optimistic perspective can be considered an asset for future planning and rehabilitation of degraded landscapes at the national level.

Soil and vegetation C stocks, soil nutrient contents, and species diversity and richness were higher in all exclosures than in communal grazing lands. This indicates that exclosures have a significant positive effect on the restoration of ecosystem services. Similar studies conducted in Ethiopia also demonstrated that the establishment of exclosures on degraded communal grazing lands contributes to the provisioning function of ecosystem services through improved animal feed and human food products, such as honey (Haile 2012); regulating services through sequestering below- and aboveground carbon (Descheemaeker et al. 2006, Girmay et al. 2009, Verdoodt et al. 2009); supporting services through improving soil formation and soil fertility (Mamo 2008, Tsetargachew 2008, Mekuria 2013); enhancing nutrient cycling and biomass production (Birhane et al. 2007); and facilitating cultural services through generating aesthetic value and use for educational purposes. Exclosures are also important for sustaining habitat and restoring vegetation composition, as well as improving indigenous plant species diversity and richness (Mengistu et al. 2005a, Abebe et al. 2006, Yami et al. 2006, Birhane et al. 2007, Muchiru et al. 2009, Hosseinzadeh et al. 2010, Verdoodt et al. 2010).

7.4 Conclusions

Restoration of degraded landscapes through establishing exclosures contributes toward a more resilient community and environment. Achieving landscape restoration objectives involving the use and management of exclosures requires institutional mechanisms such as the participation of local communities, establishment of village bylaws, support of governance systems, and joint monitoring and evaluation systems for accounting for the impacts generated from the restoration of degraded landscapes. Case studies from northern Ethiopia substantiated the importance of exclosures in restoring degraded landscapes. However, for the best use of exclosures as an means for landscape restoration, due attention should be given to the following issues: (a) identification of the best community organization to effectively manage exclosures, whether at the level of a few individuals to an entire village, hamlet, or district; (b) redefining rehabilitation objectives; (c) crafting strategies to move from conservation to enhancing economic benefits; and (d) ensuring gender equity in management and benefit sharing. Such concerns indicate the need for clarity of objectives and responsibilities in the management of exclosures, as well as the need to increase short-term benefits to attain the sustainability of exclosures.

7.5 References

Abebe, MH, G Oba, A Angassa, and RB Weladji. 2006. The role of area enclosures and fallow age in the restoration of plant diversity in Northern Ethiopia. *African Journal of Ecology* 44:507–514.

Birhane, E, D Teketay, and P Barklund. 2007. Enclosures to enhance woody species diversity in the drylands of Tigray. *East African Journal of Science* 1:136–147.

Bernazzani, P, BA Bradley, and JJ Opperman. 2012. Integrating climate change into habitat conservation plans under the U.S. Endangered Species Act. *Environmental Management* 49:1103–1114.

Bishaw, B. 2001. Deforestation and land degradation on the Ethiopian highland: A strategy for physical recovery. Paper presented at *International Conference on Contemporary Development Issues in Ethiopia, Kalamazoo, Michigan, USA. August 16–18, 2001.*

Branca, G, N McCarthy, L Lipper, and MC Jolejole. 2011. *Climate-Smart Agriculture: A Synthesis of Empirical Evidence of Food Security and Mitigation Benefits from Improved Cropland Management*. Report 3, Food and Agriculture Organization of the United Nations (FAO), Rome. 24 p.

Bullock, JM, J Aronson, AC Newton, RF Pywell, and J Rey-Benayas. 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends in Ecological Evolution* 26:541–549.

Cline, WR. 2007. *Global Warming and Agriculture: Impact Estimates by Country.* Peterson Institute for International Economics, Washington, DC. 250 p.

Descheemaeker, K, J Nyssen, J Rossi, J Poesen, M Haile, J Moeyersons, and J Deckers. 2006. Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia. *Geoderma* 132:291–314.

Doren, RF, JC Trexler, AD Gottlieb, and MC Harwell. 2009. Ecological indicators for system-wide assessment of the greater everglades ecosystem restoration program. *Ecological Indicators* 9:2–16.

Ethiopian Meteorological Service Agency. 2007. *Annual climate bulletin for the year 2007.* Ministry of Water Resources, Addis Ababa, Ethiopia.

Girmay, G, BR Singh, J Nyssen, and T Borrosen. 2009. Runoff and sediment-associated nutrient losses under different land uses in Tigray, Northern Ethiopia. *Journal of Hydrology* 376:70–80.

Grainger-Jones, E. 2012. *Climate-Smart Smallholder Agriculture: What's Different?* Occasional Paper 3, International Fund for Agricultural Development (IFAD), Rome. 20 p.

Haile, G. 2012. *Effect of Exclosure on Environment and its Socio-economic Contributions to Local People: A Case Study of Halla Exclosure, Tigray, Ethiopia*. MA thesis, Norwegian University of Life Science, Ås, Norway.

Hoff, C, S Rambal, and R Joffre. 2002. Simulating carbon and water flows and growth in a Mediterranean Evergreen *Quercus Ilex* Coppice using the FOREST-BGC model. *Forest Ecology and Management* 164:121–136.

Holl, KD, EE Crone, and CB Schultz. 2003. Landscape restoration: moving from generalities to methodologies. *Biological Science* 53:491–502.

Hosseinzadeh, G, H Jalilvand, and R Tamartash. 2010. Short term impacts of enclosure on vegetation cover, productivity and some physical and chemical soil properties. *Journal of Applied Sciences* 10:2001–2009.

IUSS Working Group WRB. 2006. *World Reference Base for Soil Resources 2006: A Framework for International Classification, Correlation, and Communication.* World Soil Resources Report 103, Food and Agriculture Organization of the United Nations (FAO), Rome. 127 p.

Keyzer, MA, and BGJS Sonneveld. 2001. The effect of soil degradation on agricultural productivity in Ethiopia: anon-paramatic regression analysis, pp. 269–292, in *Economic Policy Reforms & Sustainable Land Use in LDC's*, ed. H Heerink, H Van Keuken, and M Kurpios. Physica Verlag, Amsterdam, The Netherlands.

Mamo, K. 2008. *Enclosure as a Viable Option for Rehabilitation of Degraded Lands and Biodiversity Conservation: The Case of Kallu Woreda, Southern Wello*. Unpublished MSc thesis, Addis Ababa University, Ethiopia. 99 p.

Mekuria, W, and E Aynekulu. 2013. Exclosure land management for restoration of the soils in degraded communal grazing lands in Northern Highlands of Ethiopia. *Land Degradation and Development* 24:528–538.

Mekuria, W, E Veldkamp, M Haile, K Gebirehiwot, B Muys, and J Nyssen. 2009. Effectiveness of exclosures to control soil erosion and local community perception on soil erosion in Tigray, Ethiopia. *African Journal of Agricultural Research* 4:365–377.

Mekuria, W, E Veldkamp, T Mesfin, and R Olschewski. 2011a. Economic valuation of land restoration: The case of exclosures established on communal grazing lands in Tigray, Ethiopia. *Land Degradation and Development* 22:334–344.

Mekuria, W, E Veldkamp, MD Corre, and M Haile. 2011b. Restoration of ecosystem carbon stocks following exclosure establishment in communal grazing lands in Tigray, Ethiopia. *Soil Science Society of America Journal* 75:246–256.

Mekuria, W, and E Veldkamp. 2012. Restoration of native vegetation following exclosure establishment on communal grazing lands in Tigray, Ethiopia. *Applied Vegetation Science* 15:71–83.

Mekuria, W. 2013. Conversion of communal grazing lands into exclosures restored soil properties in the semi-arid lowlands of Northern Ethiopia. *Arid Land Research and Management* 27:153–166.

Mekuria, W, S Langan, R Johnston, B Belay, D Amare, T Gashaw, G Desta, A Noble, and A Wale. 2015. Restoring aboveground carbon and biodiversity: the case study from the Nile Basin, Ethiopia. *Forest Science and Technology* 11:86–96.

Mengistu, T, D Teketay, H Hulten, and Y Yemshaw. 2005a. The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environment* 60:259–281.

Milder, JC, T Majanen, and SJ Scherr. 2011. *Performance and Potential of Conservation Agriculture for Climate Change Adaptation and Mitigation in Sub-Saharan Africa.* Discussion Paper 6, Ecoagriculture Partners, Washington, DC. 80 p.

Millar, CI, NL Stephenson, and SL Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications* 17:2145–2151.

Minnemeyer, S, L Laestadius, N Nigel Sizer, C Saint-Laurent, and P Potapov. 2011. *A World of Opportunity for Forest and Landscape Restoration*. The Global Partnership on Forest Landscape Restoration. www.ideastransformlandscapes.org and www.wri.org/restoring-forests.

Muchiru, AN, D Western, and RS Reid. 2009. The impact of abandoned pastoral settlements on plant and nutrient succession in an African savanna ecosystem. *Journal of Arid Environments* 73:322–331.

Nedessa B, J Ali, and I Nyborg. 2005. *Exploring Ecological and Socio-economic Issues for the Improvement of Area Enclosure Management: A Case Study from Ethiopia*. Report 38, Drylands Coordination Group, Oslo, Norway. 47 p.

Olschewski, R, and P Benítez. 2005. Secondary forests as temporary carbon sinks? The economic impact of accounting methods on reforestation projects in the tropics. *Ecological Economics* 55:380–394.

Olschewski R, P Benítez, GHJ de Koning, and T Schlichter. 2005. How attractive are forest carbon sinks? Economic insights into supply and demand of certified emission reductions. *Journal of Forest Economics* 11:77–94.

Scherr, SJ. 1999. *Soil Degradation: A Threat to Developing-Country Food Security by 2020?* International Food Policy Research Institute, Discussion Paper 27, Washington, DC. 51 p.

Scherr, SJ and S Sthapit. 2009. *Mitigating Climate Change through Food and Land Use*. Worldwatch Report 179, Worldwatch Institute, Washington, DC. 44 p.

Scherr, SJ, S Shames, and R Friedman. 2012. From Climate-Smart Agriculture to Climate-Smart Landscapes. *Agriculture and Food Security* 1:12.

Snowdon, P, J Raison, H Keith, P Ritson, P Grierson, M Admas, K Montagu, BB Huiquan, and D Eamus. 2002. *Protocol for Sampling Tree and Stand Biomass.* Technical report 31, Australian Greenhouse Office, Canberra, ACT. 65 p.

Soil Survey Staff. 1996. *Keys to Soil Taxonomy.* 7th ed. US Department of Agriculture, Washington, DC. 639 p.

Tsetargachew, A. 2008. *Area Closure as a Strategy for Land Management: A Case Study at Kelala Dalacha Enclosure in the Central Rift Valley of Ethiopia*. Unpublished MSc thesis, Addis Ababa University, Ethiopia. 107 p.

UNDP (United Nations Development Program). 2002. *Human Development Report*. Report. Oxford University Press, Oxford, UK. 292 p.

UNFCCC. 2003. *Development and Transfer of Technologies.* Report of the UNFCCC workshop on enabling environments for technology transfer, Ghent, 9–10 April 2003. UNFCC Secretariat, Bonn, Germany. 49 p.

Verdoodt, A, SM Mureithi, L Ye, and EV Ranst. 2009. Chronosequence analysis of two enclosure management strategies in degraded rangeland of semi-arid Kenya. *Agriculture, Ecosystem and Environment* 129:332–339.

Verdoodt, A, SM Mureithi, and EV Ranst. 2010. Impacts of management and enclosure age on recovery of the herbaceous rangeland vegetation in semi-arid Kenya. *Journal of Arid Environments* 74:1066–1073.

World Bank. 2010. *Climate-Smart Agriculture: A Call to Action*. Report, The World Bank, Washington, DC. 24 p.

Yami, M, K Gebirehiwot, M Stein, and W Mekuria. 2006. Impact of area enclosures on density, diversity, and population structure of woody species: the case of May Ba'ati-Douga Tembien, Tigray, Ethiopia. *Ethiopian Journal of Natural Resources* 8:99–121.

Yami, M, W Mekuria W, and M Hauser. 2013. The effectiveness of village bylaws in sustainable management of community-managed exclosures in Northern Ethiopia. *Sustainability Science* 8:73–86.

Zhao, C, B Liu, S Piao, X Wang, DB Lobell, Y Huang, M Huang, Y Yao, S Bassu, P Ciais, JL Durand, J Elliott, F Ewert, IA Janssens, T Li, E Lin, Q Liu, P Martre, C Müller, S Peng, J Peñuelas, AC Ruane, D Wallach, T Wang, D Wu, Z Liu, Y Zhu, Z Zhu, and S Asseng. 2017. Temperature increase reduces global yields of major crops in four independent estimates. *PNAS* 114(35):9326–9331. https://doi.org/10.1073/pnas.1701762114