Ecosystem-Based Adaptation in Tigray, Northern Ethiopia: A Systematic Review of Interventions, Impacts, and Challenges

120

Mulubrhan Balehegn, Mitiku Haile, Chao Fu, and Wu Liang

Contents

M. Balehegn (✉)
Department of Animal, Rangeland and Wildlife Sciences, Mekelle University, Mekelle, Ethiopia
e-mail: mulubrhan.balehegn@mu.edu.et; mu.gebremikael@ufl.edu

M. Haile
Department of Land Resource Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia

C. Fu
Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

W. Liang
Research Center for World Geography and Resources, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

W. Leal Filho (ed.), *Handbook of Climate Change Resilience*,
https://doi.org/10.1007/978-3-319-93336-8_117

Abstract

The Tigray regional state in the northern part of Ethiopia has been severely affected by centuries of land degradation and climate change-induced recurrent drought and extreme weather variability. Government and people have, therefore, steadily implemented internationally recognized (Example at Rio 20 for Innovative Hunger Solutions and recently Gold Medal Winner at the World Future Council award for Best policy in Combating Desertification and Land Degradation: The World's Best Policies https://www.worldfuturecouncil.org/p/champions/) land rehabilitation and ecosystem-based adaptation (EBA) programs. Despite the international recognition for the successes, the specifics of the different interventions implemented, the impacts observed, challenges encountered have not been well articulated and communicated, in a way that would enable other similar regions to learn from the experiences of Tigray region of Ethiopia. In this chapter, we reviewed 170 publications on 30 EBA interventions in 400 sites in Tigray. Interventions fall in either of the following categories: Soil and Water Conservation (SWC) (62.69%), Biological Rehabilitation (BR) (18.41%), Water Harvesting and Production (WHP) (7.46%), Soil Fertility Improvement (6.22%), Conservation Agriculture (3.48%), and Integrated Watershed Management (1.74%). While many studies reported impressive biophysical changes, e.g., decrease in runoff and increased sediment deposition (in 63.93% of cases), farmer-relevant impacts such as improvements in crop and livestock yields and income/livelihoods have been quantified only in 8.46%, 1.6%, and 4.16% of cases, respectively, implying that implementers are failing to communicate impacts, causing a missed opportunity for fast dissemination and mobilization in other similar places. The most successful interventions include exclosures and variety of soil and water conservation measures (mainly stone bunds), while those that showed limited positive impacts are water harvesting and production schemes. Popular support and capitalization on locally available resources are the most cited reasons for success of interventions, while overambitious and myopic project planning, top-down approach, limited technical skills are common challenges encountered. In this chapter, we summarized one of the most successful cases of EBA and land rehabilitation intervention in the world, identified strengths, weaknesses, challenges, and suggested solutions in a way that could enable other communities learn from the EBA experiences of Tigrian farmers and government.

Keywords

EBA · Land rehabilitation · Tigray · Northern Ethiopia · Land degradation

Introduction

Northern Ethiopia has historically been under extreme demographic influence, civil war, and climate change that increased the occurrence of drought and extreme weather variability and concomitant environmental degradation (Conway 2000). Perhaps nowhere in the world is land degradation problem more manifest than in the marginal highlands of northern Ethiopia (Hengsdijk et al. 2005), with a huge cost and economic implication (Haregeweyn et al. 2008a). Some of the worst human calamities caused by drought and subsequent famines have been reported in the northern Ethiopian regions of Tigray, Amhara, and Afar, so much so that the region has been associated with famine and misery in popular imagination. Such challenges have made people and government in northern Ethiopia to implement steady ecosystem-based adaptation (EBA) and community-based land rehabilitation and conservation programs, with impressive and internationally recognized success (Bewket 2007). The interventions implemented in northern Ethiopia utilize biodiversity and ecosystem services to support climate change adaptation and enhance environmental rehabilitation, making them typical cases of EBA (Munang et al. 2013).

Nonetheless, despite northern Ethiopia being repeatedly recognized for its efforts-impacts of its interventions (https://www.worldfuturecouncil.org/p/champions/), information on what actually has been changed and what has been achieved is only available in the form of results of dispersed studies that evaluate the impact of different interventions on wide variety of environmental and social variables (Gebremeskel et al. 2017). So far, impacts brought about through different interventions, the challenges encountered, and possible future solutions have not been analyzed and articulated in a way that would enable sharing of experiences with other communities (Gebremeskel et al. 2017). Therefore, studies undertaken on different EBA interventions in the Tigray regional state with the objective of identifying understanding the EBA interventions, their impacts, challenges encountered in implementation, and recommendations for better successful implementation in the future. Moreover, the study contributes towards evidence on effectiveness of EBA that is generally limited worldwide and concentrated only in developed countries (Doswald et al. 2014) and provides an analysis of different factors that affect the effectiveness of EBA interventions based on cases from northern Ethiopia.

Materials and Methods

Description of the Study Area

Tigray regional state is one of the nine regional states in Ethiopia located at the northern most extreme of the country (Fig. 1) between 12°15′ and 14°50′N and between 36° 27′ and 39° 59′E with an area of 80,000 km^2. It is surrounded by Sudan in the west, Eritrea in the north, and the Ethiopian regions of Amhara and Afar in the

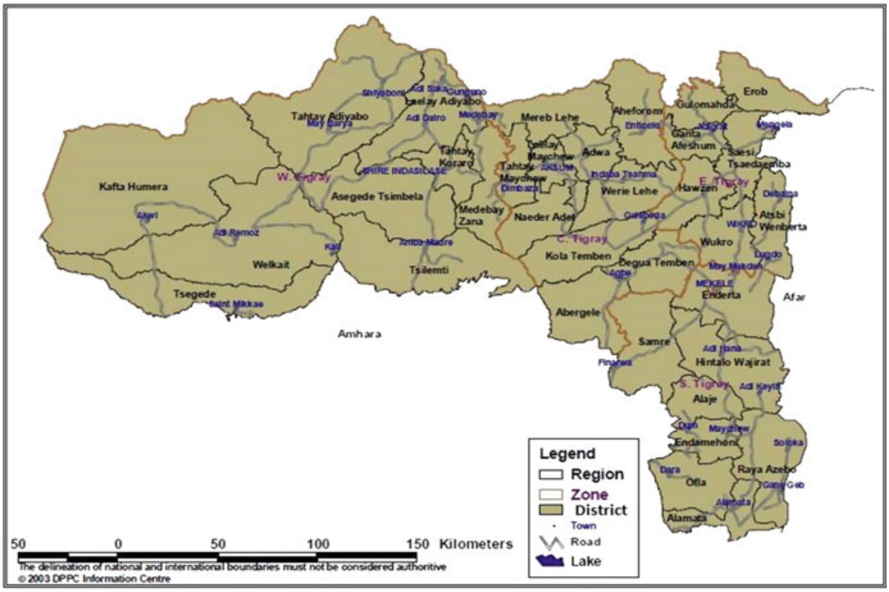

Fig. 1 The Tigray regional state showing its administrative units

south and east, respectively. Tigray is characterized by undulating terrain and steep slopes with altitude varying from 500 to 4000 m.a.s.l. (Gebremeskel et al. 2017). The agroecology is semi-arid with distinct dry and wet seasons and rainfall ranging 200–1000 mm and with an average annual temperature of 18 °C (Hagos et al. 1999).

The land use types dominant in Tigray include croplands, exclosures, remnant forests, villages, and built-up areas. Thirteen major soil types are identified in Tigray: *cambisols*, *rendzinas*, *lithosols*, *acrisols*, *fluvisols*, *luvisols*, *regosols*, *nitosols*, arenosols, vertisols, xerosols, solonchaks, and andosol (Nyssen et al. 2008a). The geological formations consist of Precambrian metavolcanics and Mesozoic sedimentary rocks such as Adigrat sandstone, Antalo limestone, Agula shales, and Amba Aradam sandstone, which in turn are intruded by Cenozoic dolerite dykes/sills (Haregeweyn et al. 2008b).

Tigray has a population of 4.4 million growing at 3% annually (CSA 2010). The farming system is dominated by small-scale rainfed agriculture, which utilizes traditional crop and livestock production technologies (Hagos et al. 2016). Approximately 90% of the population depends on the centuries-old plow-based subsistence cultivation, currently having 1.2 ha average landholdings per household (Pender and Gebremedhin 2007). Agriculture contributes to 60% of the regional total gross domestic product (Hagos et al. 2016). Dominant cereal crops grown are *tef* (*Eragrostis tef*), barley (*Hordeum vulgare* L.), wheat (*Triticum sp.*), sorghum (*Sorghum bicolor*), and maize (*Zea mays*), accompanied by leguminous crops such as field peas (*Pisum sativum*), chickpeas (*Cicer arietinum*), and horse bean (*Vicia faba*). Gesho (*Rhamnus prinoides*). Cattle, sheep, goat, equines, beehives, and poultry are dominantly found in livestock types in Tigray.

Methods

Selection of Studies and Records

Published studies were searched from the Web of Science and Google Scholar Databases using relevant key words. Moreover, gray literature or office and field reports by different organizations working in the EBA issues in the Tigray, Masters/MA, PhD level unpublished theses and dissertations have also been included. Though there was no restriction in the years for publication of studies and reports, most of the 170 identified studies fall within the years 1997–2017. Only studies or peer reviewed publications that have been published in journals indexed by the Web of Science, Scopus, African Journals OnLine, and other legitimate indexing services were included, and those published in the so-called predatory journals have been excluded, as their quality have been repeatedly questioned (Balehegn 2017a).

Evaluation of EBA Interventions

EBA interventions were first categorized into any of the six categories namely: (1) Biological Rehabilitation (BR): Those that intend to enhance or improve the biological potential of degraded grazing lands, farmlands, etc.; (2) Conservation Agriculture (CA): Types of agriculture or farming that tried to maximize the conservation of moisture for improved yield; (3) Integrated Watershed Management (IWM) catchment or watershed level approaches that implement combinations of many interventions for an overall ecological and livelihoods improvement; (4) Soil Fertility Improvement (SFI), which included variety of interventions that aim to improve the fertility status of degraded farmlands; (5) Soil and Water Conservation (SWC), interventions aimed at conserving soil and water or protecting soil from erosion; and (6) Water Harvesting and Production (WHP), interventions that intend to conserve water from loss or extract more water for agricultural and other uses. The observed impacts of EBA interventions were also categorized into 11 general categories (Fig. 5) namely: (1) Enhanced drought and climate change adaptation (EDCCA), (2) Enhanced soil characteristics (ESC), (3) Enhanced vegetation (EV), (4) Improved carbon stocks (ICS), (5) Improved crop yields (ICY), (6) Improved income and livelihoods (IIaL), (7) Improved livestock productivity (ILsP), (8) Improved wildlife diversity (IWD), (9) Improved water harvesting and use efficiency (IWHUE), (10) Reduced runoff and increased sediment deposition (RRISD), and (11) Others. Moreover, for most of the EBA interventions, main challenges encountered during the implementation, solutions recommended or implemented have also been identified (Table 8).

Results and Discussions

Types of EBA Interventions

A total of 30 types of EBA interventions including SWC ($n = 16$) followed by WHE ($n = 10$), BR ($n = 10$), CA (n = 7) and SFI ($n = 3$) have been reported. The typology of the different interventions is given in Fig. 2. The EBA interventions according to the percentage of cases reported (total number = 402) are SWC (62.69%), BR (18.41%), WHP (7.46%), SFI (6.22%), CA (3.48%), and IWM (1.74%) (Fig. 3). The larger diversity of SWC interventions is because of the diverse agro-ecological setting in northern Ethiopia that requires different solutions. Moreover, soil erosion and land degradation have always been the most important environmental problems (Hurni 1988) with serious economic consequences such as, for example, causing a loss of 3.4 million Euros per year, just from the erosion caused loss of N and P in Tigray (Haregeweyn et al. 2008a). As a result therefore, SWC interventions have been the commonest types of EBA interventions in northern Ethiopia, with about 522, 600 ha of land already covered by some form of SWC interventions, mainly stone bunds from 1991 to 2002 (Nyssen et al. 2007). Exclosures are the second most commonly implemented and studied interventions. Currently, there are about three million hectares of land under exclosure management all over Ethiopia (Lemenih et al. 2014), with most of it (around 1.2 million hectares) of exclosures being in Tigray (Tetemke et al. 2017).

The description, purposes, and sites for implementation of the different EBA interventions is given in Table 1. Some examples graphical representations of EBA interventions are also given in Fig. 4.

Impact of Interventions

The most commonly reported impact is reduction in runoff and increase in sediment deposition (461 cases) followed by improved crop yield (61 cases) and enhanced vegetation (49 cases) (Fig. 3). Other impacts, reported to a lesser extent also included impacts on income, livestock productivity, soil fertility, carbon stocks and others (Fig. 3).

Apart from limited number of studies (30 cases), which tried to quantify and demonstrate the economic or livelihood impact of interventions, most studies demonstrated only biophysical impacts on soil, vegetation and water. This is probably because of the methodological difficulties of differentiating the impact of the EBA interventions on the livelihoods and income (Haregeweyn et al. 2015) but is critical problem because, the emphasis on biophysical impacts with little consideration on

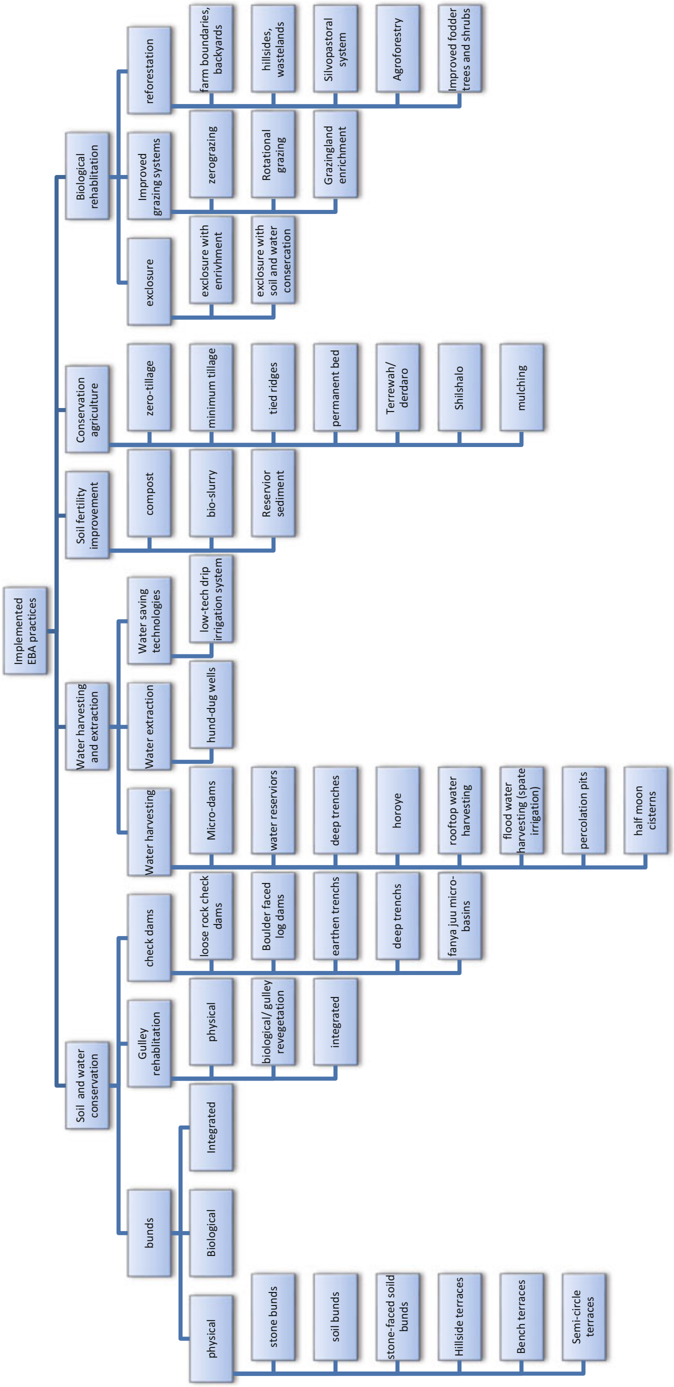

Fig. 2 Typology of ecosystem-based adaptation techniques implemented in northern Ethiopia

the social and economic benefits of interventions makes it difficult to provide evidence for convincing policy makers in expanding the implementation of the EBA practices and popularizing the practices among local communities (Awulachew et al. 2005). Even when it is currently difficult to quantify economic and livelihood benefits, as ecological improvement will take time to manifest as livelihood improvement, it is important that modeling studies be undertaken to generate evidence for livelihood impacts of interventions, unless and otherwise it will be difficult to convince farmers (Balana et al. 2010).

Impacts of Biological Rehabilitation

Positive impacts as a result of the most common biological rehabilitation interventions – exclosures – include improvements in: litter accumulation (1802–2108.57%), total organic carbon (15–64%), available Nitrogen (187–5125%); soil phosphorus (290–1150%), and other soil chemical characteristics (Table 2). Similarly, exclosures have resulted into improved vegetation attributes including: herbaceous cover (329.27%), herbaceous species diversity (31–50%), woody species cover (436%), woody species diversity (50–81%), and other vegetation attributes including species richness, vegetation density, basal cover and ground cover, and bird and mammal species diversity (Table 2). Reduction in soil erosion (46–79%), runoff (83–95), and

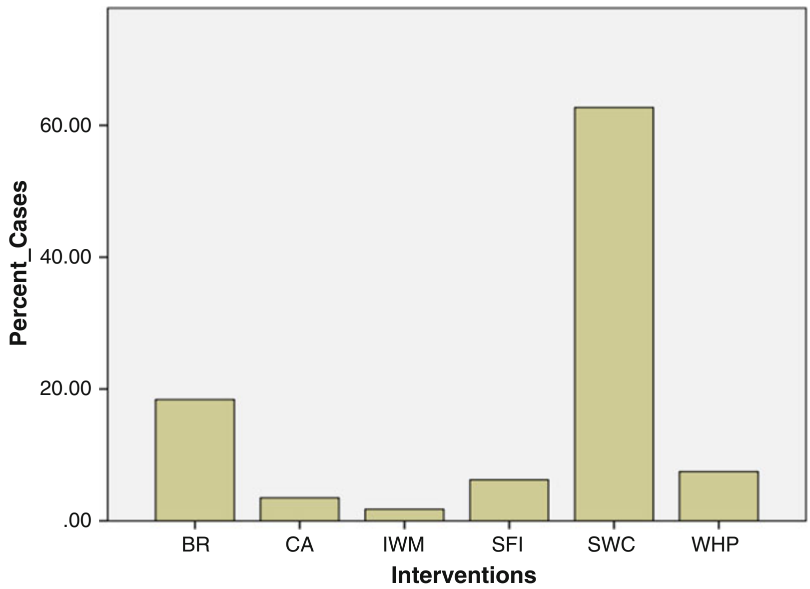

Fig. 3 Percentage cases of studied interventions. *SWC* Soil and water conservation, *WHP* Water harvesting and production, *SFI* Soil fertility improvement, *EA* Ecological Agriculture, *BR* Biological rehabilitation, *IWM* Integrated watershed management

Table 1 EBA interventions implemented in northern Ethiopia and their descriptions

EBA/Subtype	Description of the intervention	Objectives or aims	Sites or areas applied	Sample references
Biological rehabilitation				
Exclosures	Areas closed off from human and livestock disturbance; may or may not be accompanied with enrichment or planting of tree species or soil and water conservation practices	To promote natural regeneration of degraded grazing lands and hillsides	Degraded hillsides	Aerts et al. (2009)
Zero-grazing	A system of grazing where livestock are restricted in a small space (usually in backyards or barns) and fodder is cut and carried to where animals are, instead of animals freely grazing on grazing lands	To prevent overgrazing and destruction of conservation structures and young seedlings by livestock	Degraded grazing lands	Gebreyohannes and Hailemariam (2011)
Silvopastures	Planting or enhancing fodder or other multipurpose trees in pasturelands, farm boundaries, backyards, etc.	To improve livestock feed availability while providing other multipurpose benefits, e.g., fuel wood	Grazing land, farmland boundaries, wastelands, backyards	Balehegn (2017b)
On farm agroforestry	The use, planting and enhancement of trees on farmlands or farmland boundaries	Improve soil fertility, serve as wind break and prevention of pests while providing multiple benefits	Farmlands and farmland boundaries	Ernstberger (2017)
Reforestation/ enrichment	Planting of seedling of exotic or indigenous tree species or reseeding of seeds of trees and herbaceous plants into degraded lands	For rehabilitating degraded area, recovering plant cover	Degraded hillsides, degraded rangelands	Meaza et al. (2016)

(*continued*)

Table 1 (continued)

EBA/Subtype	Description of the intervention	Objectives or aims	Sites or areas applied	Sample references
Conservation agriculture				
Zero-tillage	Not tilling the land before sowing, may involve weeding or removal of unnecessary vegetation	To reduce moisture loss and soil disturbance due to excessive plowing	Drought-affected farmlands	McHugh et al. (2007)
Minimum tillage	Also called conservation plowing or noninversion tillage (e.g., reduced plowing which minimizes the disruption of soil structure. The frequency of plowing is reduced to less than the 3–12 times practiced traditionally for different crops in northern Ethiopia	To improve soil physical characteristics and moisture content	Drought-affected farmlands	Tesfahunegn (2015)
Terrewah	Traditional plowing followed by making every 1.5–2 m contour furrows. Furrows are made at 2–4 m intervals along the contour the same day after planting, especially practiced for teff (*Eragrostis teff*)	To conserver moisture on farm and prevent runoff	Farmlands	Araya et al. (2016a)
Shilshalo	A traditional plowing where contour furrows are created within the standing crop (mostly sorghum and maize) during second weeding operation	To conserve moisture on farm and prevent runoff, reduce weed infestation	Sorghum and maize fields	Nyssen et al. (2010)
Derdero	Bed furrows prepared along contour using the	Conserving water on farm	Farmlands	Nyssen et al. (2010)

(*continued*)

Table 1 (continued)

EBA/Subtype	Description of the intervention	Objectives or aims	Sites or areas applied	Sample references
	traditional *marasha (Plowsahre)* at the last tillage operation or after farmers broadcast seeds over the farmland			
Tied ridges	Small earthen *ridges*, 15–20 cm high, with an upslope furrow which accommodates runoff from a catchment strip between the *ridges*	Conserve water on farm, reduce amount of moisture lost due to excessive plowing	Farmlands	Grum et al. (2017a)
Crop residue mulching	Leaving crop-residue on the farm, after harvest so that they serve as mulch against evaporation of moisture	To conserve residual moisture	Drought-affected farmlands	Araya and Stroosnijder (2010)
Integrated watershed management	A holistic watershed or catchment development that integrates various interventions with in a catchment while utilizing synergies and reducing competitiveness among interventions	Overall ecological rehabilitation, improvement of yields, and adaptation to natural challenges	Degraded watersheds	Alemayehu et al. (2009)
Soil fertility improvement				
Compost	Decaying domestic organic wastes, weeds, and plant materials to use them for fertilizing farmlands	Improve fertility of degraded farmlands with low cost input	Degraded or infertile farmlands	Edwards (2007a)
Bioslurry	A byproduct of an aerobic fermentation of livestock excreta or dung in a biogas digester	Used as a fertilizer while the biogas used as a source of fuel	Farmlands	Edwards (2012)

(*continued*)

Table 1 (continued)

EBA/Subtype	Description of the intervention	Objectives or aims	Sites or areas applied	Sample references
Reservoir sediment	Sediment harvested from the bottom of reservoirs when they dry up during the dry season and applied to farmlands	To utilize nutrients leached from upper soil and stored in reservoirs for land reclamation	Degraded farmlands	Girmay et al. (2012)
Soil and water conservation				
Earthen trenches	Or simply trenches are ditches dug on the path of an erosion or a catchment	To trap sediment, reduce runoff or erosion	On high erosion areas (grazing lands, hillsides)	Taye et al. (2014)
Traditional *Daget*	Traditionally established by farmers as untilled strip of about 2 m wide at a lower plot limit in a slopping farmland. The grass in this strip is allowed to grow year after year	The strip is intended to reduced runoff velocity and allows water to infiltrate and sediment to be trapped	At the edge or lower strip of farmlands	Nyssen et al. (2000)
Stone bunds/ terraces	Stone structures constructed along a contour in a slopping land (usually hillsides and slopping farmlands)	To reduce erosion or runoff	On hillsides, sloppy farmlands	Nyssen et al. (2008b)
Soil bunds	Soil-based structures constructed along a contour in a slopping land (usually only on slightly sloped farmlands)	To reduce erosion and runoff	On a slightly slopping farmland	Teshome et al. (2013)
Gabion check dams	Check dams constructed using rocks and reinforced by gabion or wire mesh for increased strength or resistance	To control gulley expansion, trap sediment, and conserve water	On gullies, streams and eroded areas	Mekonnen et al. (2015)

(*continued*)

Table 1 (continued)

EBA/Subtype	Description of the intervention	Objectives or aims	Sites or areas applied	Sample references
Boulder-faced log dams	Dams constructed by embedding two parallel logs with a spacing that varies between 5 and 25 cm, lifting the logs approximately 0.50–1 m above bed and facing their upper side with spaced boulders (0.3–0.7 m across) that rested on coarse bed load	To counter the destruction of gabion dams caused by abrasion in heavy currents	In rivers and streams with heavy currents	Nyssen et al. (2017)
Loose rock check dams	Check dams constructed across small and medium sized streams using only rocks and also mud or soil	To control gulley expansion or rehabilitate gullies	On gullies	Nyssen et al. (2004b)
Water harvesting and production				
Horeye	Trapezoidal ponds with their floors and sides sometimes covered with plastic, riprap, or compacted to prevent seepage	To harvest water at household level from small catchments	On wasteland with catchment	Gebremeskel et al. (2017)
Micro-dam reservoirs	Small dams built in catchments and valleys to reserve water during the rainy season for using it in the dry season	Harvesting and reserving water for irrigation and livestock use	On catchments and valley bottoms	Berhane et al. (2016a, b)
Percolation pond	Pits and ditches of various sizes and shapes, dug or constructed for the sole purpose of allowing runoff to percolate	Increase ground water availability in downstream areas	On wastelands, degraded areas upstream	Grum et al. (2017b)
Deep trench	Deep trenches at lower part of a catchment or across the slop of a catchment dug to harvest water and silt during	To control runoff, trap silt, and enhance groundwater recharge processes	On road sides, degraded areas, farmland sides	Woldearegay et al. (2015)

(*continued*)

Table 1 (continued)

EBA/Subtype	Description of the intervention	Objectives or aims	Sites or areas applied	Sample references
Hand-dug wells	Wells dug deep into the ground to access and collect ground water	To provide water for domestic use and irrigation	On backyards, near farmlands in the lower section of catchments	Woldearegay and Van Steenbergen (2015)
Roof water harvesting	A simple system and structure to harvest water from roofs and store it in underground or above ground concrete tankers or any other form of water storage facility	To harvest rain water that would otherwise be lost	In urban and peri-urban areas	Ham (2008)
Spate irrigation	The diversion of seasonal floods to irrigate farmlands	To utilize excessive flood water for growing crops	Dryland farming systems	Hiben and Tesfa-alem (2014)
Low cost family drip irrigation	Low cost family-based drip irrigation systems that use small plastic tubes and water conserving structures to save water	Saving water	On backyard and highly fertile soils	Waktola (2007)

improvement in other soil and water variables such as rain percolation, and sediment accumulation are also some of the impacts of exclosures that have been measured in various studies (Table 2).

Though limited in numbers, economic-related impacts have also been quantified for exclosures. These include improvement in yield of economically important products such as Frank incense from *Boswellia paprifera* tree (43.9%), improvement in livestock productivity (20%), and overall increase in net value of land as a result of conversion to exclosures (28%). Though numerical quantification is lacking, exclosures have also improved the income of poor families through the production of honey in exclosures and sell of grass (Meaza et al. 2016). In fact, a study by Babulo et al. (2009) indicated that products from exclosures including (honey, fuel wood, grass, etc.) account for 15% of the overall average forest environmental income in Tigray.

Fig. 4 Different EBA interventions implemented in Tigray (Top row right to left: Gulley treatment, stone bunds, integrated gulley treatment, zero-grazing (cut and carry from exclosures). Middle row: Reservoirs, hand-dug wells, and river diversion). Bottom row: Treated gulley, exclosure enriched with drought-tolerant halophytes, earth sided deep trenches, the derdero system of plowing)

Table 2 Impacts of biological rehabilitation interventions in northern Ethiopia (Sampled studies showing impacts on various variables)

Observed impact	Untreated	Treated	Percentage change	Description of the study setting	Sampled references
Exclosures					
Litter biomass	17.5 (g/m^2)	386.5 (g/m^2)	2108.57%	Old exclosure compared with freely grazed land; values average for two sites	Descheemaeker et al. (2009a)
Available organic matter	9 g/m^2	148.8 g/m^2	1553.33%	Average value for exclosures of different ages, comparison with unprotected grazing land	Descheemaeker et al. (2006)
Carbon stock	7.76 mg ha^{-1}	22.29 mg ha^{-1}	187.24%	Average value for exclosures of different ages, comparison with unprotected grazing land	Solomon et al. (2017)
Soil organic carbon	54 mg C ha^{-1}	74 mg C ha^{-1}	37.04%	0–40 cm soil depth, comparison with cultivable land	Girmay and Singh (2012)
Available total nitrogen	0.2 g/m^2	4.32 g/m^2	2060.00%	Average value for exclosures of different ages, comparison with unprotected grazing land	Descheemaeker et al. (2006)
Available phosphorus	0.02 g/m^2	0.078 g/m^2	290.00%	Average value for exclosures of different ages, comparison with unprotected grazing land	Descheemaeker et al. (2006)
Soil potassium	0.06 (g/m^2)	2.995 (g/m^2)	4891.67%	Exclosure compared with freely grazed land; values average for two sites	Descheemaeker et al. (2009a)
Soil calcium	1.7	70.65	4055.88%	Exclosure compared with freely grazed land; values average for two sites	Descheemaeker et al. (2009a)
Soil magnesium	0.12 (g/m^2)	3.85 (g/m^2)	3108.33%	Exclosure compared with freely grazed land; values average for two sites	Descheemaeker et al. (2009a)
Soil sodium	0.0035 (g/m^2)	0.29 (g/m^2)	8185.71%	Exclosure compared with freely grazed land; values average for two sites	Descheemaeker et al. (2009a)
Soil pH	6.25	7.2	–	Seven-year exclosure average value for soil depth 0–50 cm, comparison with free grazing land	Mekuria et al. (2017)
Mycorrhiyzal colonization	1.763*105/g soil	4.39*105/g soil	149.01%	Average value for exclosures of different ages, comparison with unprotected grazing land	Birhane et al. (2017)
Woody plant canopy cover	6%	32.16%	436.00%	Average value for 5-year and 10-year-old exclosure and comparison with freely grazing land	Mekuria et al. (2007)

Woody species diversity	2.97	5.4	81.82%	Exclosures of age 5–10 years compared with adjacent grazing lands	Yayneshet et al. (2009)
Ground cover	7%	44.83%	540.43%	Average value for 5-year and 10-year-old exclosure and comparison with freely grazing land	Mekuria et al. (2007)
Above ground biomass	2 mg/ha	15 mg/ha	650.00%	Average value for 20-years-old exclosure compared with adjacent grazing land	Mekuria and Veldkamp (2012)
Herbaceous species diversity	2.70	4.00	48.15%	Exclosures of age 5–10 years compared with adjacent grazing lands	Yayneshet et al. (2009)
Herbaceous basal cover	0.41%	1.76%	329.27%	Ten years exclosure compared with freely grazed land, average values from three locations or sites	Abesha (2014)
Common bird species with forests	5%	20%	300.00%	Exclosures compared with free grazing land	Aerts et al. (2008)
Number of large mammals	0	24		29 year exclosure compared with freely grazed land	Yami et al. (2007)
Runoff	6 times higher		−83%	Cultivated land compared with exclosure	Girmay et al. (2009)
Soil loss	68.03 t/ha/year	36.7 t/ha/year	−46.05%	Average value for 5-year and 10-year old exclosure and comparison with freely grazing land	Mekuria et al. (2007)
Evapotranspiration	358 mm	549 mm	53.35%	Exclosures from three sites with exclosures 5–20 years old	Descheemaeker et al. (2009b)
Frankincense yield from *Boswelia papirifera*	288 g/tree/year	414.58 g/tree/year	43.95%	Exclosures compared to areas open for livestock and people	Tilahun et al. (2011)
Livestock fodder		5000 kg/ha more		Exclosures compared to freely grazed land	Asres (2012)
Shannon Wiener Diversity Index (H′) for honey bee flora	0.45	0.875	94.4%%	Exclosures compared to freely grazed land. Values are average for dry and wet seasons	Teklay (2011)
Livestock water productivity		20% higher water productivity	20%	Creating exclosure on 40% of the land in a study site	Descheemaeker et al. (2010)
Net present value		28% higher (837 US $)	28%	Net present value exclosures compared with wheat farms	Mekuria et al. (2011)

(*continued*)

Table 2 (continued)

Observed impact	Untreated	Treated	Percentage change	Description of the study setting	Sampled references
Silvopastures					
Livestock productivity		Replace 50% concentrate	50%	Freed from silvopastoral fodder trees helped replace 50% concentrate feed while improving goat productivity	Balehegn et al. (2015)
Total nitrogen	1.6 mg/ha	3.5 mg/ha	118.75%	Silvopasture compared with rainfed farmland	Gelaw et al. (2015a)
Total organic carbon	16.1 mg/ha	39.1 mg/ha	142.86%	Silvopasture compared with rainfed farmland	Gelaw et al. (2015a)
Agroforestry					
Total nitrogen	0.34 g/kg	0.655 g/kg	92.65%	Agroforestry trees on farmland compared with rainfed farmland with not trees	Gelaw et al. (2015a)
Soil organic carbon	3.2 g/kg	5.95 g/kg	85.94%	Agroforestry trees on farmland compared with rainfed farmland with not trees	Gelaw et al. (2015a)
Soil quality indices (SQI)	0.47 g/kg	0.58 g/kg	23.40%	Agroforestry trees on farmland compared with rainfed farmland with not trees	Gelaw et al. (2015b)
Density of *Feidheria albida*	12.15 trees/ha	13.56 trees/ha	11.60%	On farm agroforestry compared with exclosures, values are mean for two sites	Noulekoun et al. (2017)
Reforestation					
Income from grasses		1381/ha/yr	–	Average value from four sites and 3 years	Meaza et al. (2016)
Income from timber		1722/ha/yr	–	Average value from four sites and 3 years	Meaza et al. (2016)
Erosion		15% less	–	A modeling study	Hengsdijk et al. (2005)
Soil carbon	10.7 kg/mg soil	18.0 kg/mg soil	68.22%	Restricted grazing lands compared with free grazing traditional land	Rimhanen et al. (2016)

All these improvements observed as a result of exclosure are mainly due to removal of overgrazing that not only cause removal of vegetation but also physically disturb soil structure making soil unsuitable for natural recruitment, ultimately contributing to land degradation. In the specific case of northern Ethiopia, traditional free-grazing system has contributed to the steady degradation of land that has taken place in the highlands of Ethiopia for centuries (Mekuria et al. 2007; Taddese 2001) and has resulted in continuous decline in the availability of livestock feed and other ecosystem services from natural rangelands (Gebremedhin et al. 2004). Free-grazing system did not only result in increased land degradation but also has limited the effectiveness of human endeavor in rehabilitating degraded areas through the physical destruction of soil and water conservation structures (Meshesha et al. 2012). Many communities in northern Ethiopia have therefore implemented the exclosure intervention and have voluntarily established traditional local by-laws which helped in enforcing strict protection of exclosures from livestock and human disturbance (Yami et al. 2013). Economic and ecological benefits accrued from exclosures, however, depend on the age of exclosures, where at least 7 years of exclosure is needed before significant improvements in soil physical and chemical characteristics can be detected (Mekuria et al. 2017). Therefore, it is important for planners and communities to understand that benefits may not be realized with in short period of time.

Similar to exclosures, other biological rehabilitation interventions including silvopastures, agroforestry, and plantations or reforestation have resulted in improvements such as increase in soil nitrogen, soil carbon, vegetation attributes, and farmland and livestock productivity, and even income (Table 2). These interventions act by increasing the number of multipurpose trees planted on farms, farm boundaries, wastelands, hillsides, and other similar areas. Specific multipurpose trees such as *Ficus thonningii* (Balehegn 2017b), *Feidherbia albida* (Gelaw et al. 2015a), *Acacia etbica* (Yayneshet et al. 2008) introduced in agroforestry and silvopastoral systems have been observed to result in ecological and economic improvements such as improved soil fertility (Gelaw et al. 2014), livestock productivity (Balehegn et al. 2014), and income (Meaza et al. 2016).

Impact of Conservation Agriculture Interventions

The different quantified positive impacts of conservation agriculture include reduction in runoff by *Derdaro* (49–82%), mulching (64.44%), permanent beds (60.49%), *Shilshalo* (41.65%), *tied ridges* (56%) and combination of tied ridges, straw mulch, and effective microorganisms (80.85%) (Table 3). Reduction in runoff has also resulted in the expected reduction in soil loss from farmlands at rates of 53–78.5% for *Derdero*, 78.89% for permanent beds, 21–61.03% for *Shilshalo*, and 87% for combination of *Terrrewah*, straw mulch, and effective microorganisms (Table 3). The different conservation agriculture interventions and their combinations have also resulted in reduction in loss of

Table 3 Impact of conservation agriculture interventions in Northern Ethiopia

Interventions	Impacts	Untreated	Treated	Percentage change	Description of the study setting	References
Derdaro	Runoff	91.6 mm	46.3 mm	−49.45%	Derdero compared with conservation tillage	Araya et al. (2011)
	Soil loss	30 t/ha	14 t/ha	−53.33	Terrewah compared with traditional plowing over 9 year average	Araya et al. (2016b)
	Crop yield	1.51 t/ha	2.03 t/ha	34.43%	Derdaro compared with conventional plowing, grain yield is average for 9 years for teff, wheat, barley, and grass pea)	Araya et al. (2016a, b)
	Straw yield	3.54 t/ha	4.81 t/ha	35.8%	Derdaro compared with conventional plowing, straw yield is average for 9 years for wheat and teff	Araya et al. (2016a, b)
Mulching	Runoff	67.2 mm	20.5 mm	−69.49%	Mulching compared with unmulched control. Values are average for 4 years	Araya and Stroosnijder (2010)
	Barley yield	1262.25 kg/ha	1271.33 kg/ha	0.71%	Mulching compared with unmulched control. Values are average for 4 years	Araya and Stroosnijder (2010)
Permanent bed	Runoff	653 m^3/ha	255 m^3/ha	−60.94%	Permanent bed compared with traditional plowing	Gebreegziabher et al. (2009)
	Soil loss		81% less	−81%	Permanent beds compared with conventional plowing	Nyssen et al. (2010)
Terewah	Runoff		11% less	−11%	Terewah compared with conventional tillage	Nyssen et al. (2010)
	Soil loss	19.5t/ha	7.6 t/ha	−61.03%	Terrewah compared with traditional plowing	Gebreegziabher et al. (2009)
	Crop yield	1.51 t/ha	1.78 t/ha	17.88%	Terrewah compared with conventional plowing, grain yield is average for 9 years for teff, wheat, barley, and grass pea	Araya et al. (2016a, b)
	Straw yield	3.54 t/ha	4.51 t/ha	27.4%	Terrewah compared with conventional plowing, straw yield is average for 9 years for wheat and teff	Araya et al. (2016a, b)

Shilshalo	Sorghum yield	1.4 mg/ha	1.78 mg/ha	21.35%	Tied ridges compared with flat tillage	Brhane et al. (2006)
	Sorghum stover yield	5.29 mg/ha	7.02 mg/ha	32.7%	Tied ridges compared with flat tillage	Brhane et al. (2006)
Terrewah, straw mulch, and effective microorganism	Soil loss	90.6 kg/ha	11.7 kg/ha	−87.07%	Combination of treatments compared with no treatment	Grum et al. (2017a)
	Total N loss	364.1 g/ha	98.8 g/ha	−72.86%	Combination of treatments compared with no treatment	Grum et al. (2017a)
	Total P loss	259.2 g/ha	62.8 g/ha	−75.77%	Combination of treatments compared with no treatment	Grum et al. (2017a)
Tied ridges	Runoff	67.2 mm	29.5 mm	−56.10%	Tied ridges compared with conventional tillage. Values are average for 4 years	Araya and Stroosnijder (2010)
	Barley yield	1262.25 kg/ha	1784.5 kg/ha	41.37%	Tied ridges compared with conventional tillage. Values are average for 4 years	Araya and Stroosnijder (2010)
	Soil water content		45.5% higher	45.5%	Tied ridges compared with flat tillage	Brhane et al. (2006)
	Sorghum grain yield	1.4 mg/ha	2.52 mg/ha	80%	Tied ridges compared with flat tillage	Brhane et al. (2006)
	Soghum stover yield	5.29 mg/ha	10.31 mg/ha	94.89%	Tied ridges compared with flat tillage	Brhane et al. (2006)
Tied ridges, straw mulch, and effective microorganism	Runoff	4.7 mm	0.9 mm	−80.85%	Combination of treatments compared with no treatment	Grum et al. (2017a)

soil nutrients including nitrogen and phosphorus. All these positive impacts have eventually resulted in an increase in yields of different crops including *Derdaro* (34–48%), *Shilshalo* (17.88–21.35%), and tied ridges (80–94.89%) (Table 3).

These improvements are achieved because the simple interventions of changing how land is tilled resulted in artificially made micro-basins that conserve soil moisture and reduce the loss of soil and nutrients from farmlands (Brhane et al. 2006). For instance, a simple tide ridging during plowing resulted in an increase of soil water content by 45.5% (Brhane et al. 2006). Similar improvements in water balance, crop productivity, and reduction in runoff and soil loss, due to conservation agriculture interventions, have also been observed elsewhere (McHugh et al. 2007).

Impact of Water Harvesting Interventions

Various water harvesting interventions including micro-dam reservoirs, river diversion, ground water production, and various catchment-level water harvesting structures including deep trenches, hand-dug wells (Woldearegay and Van Steenbergen 2015) have improved the available water for agriculture and domestic use, while reducing runoff and soil loss. The increased water availability for agriculture has inevitably resulted in an increase in income of up to 50% (micro-dam reservoirs), 50% (river diversion), and 50% (ground water development schemes) (Table 4). Catchment level integrated water harvesting schemes have also resulted in decrease in runoff by 43% and catchment level sediment yield by 54.5% (Table 3). Other reported impacts include increase in crop yields ranging from 71% to 233.3% for various crop types as a result of implementation of spate irrigation schemes (Table 3). Spate irrigation's positive impact is particularly important because there is about 9265.95 million meter^3 of flood water and 661853.6 ha of arable and 695,000 ha of communal land that can be irrigated using spate irrigation (Yazew 2015).

Impacts of Soil and Water Conservation

The most common types of soil and water conservation interventions (stone bunds), have resulted in improvements of: soil organic matter content (10–100.1%), soil nitrogen (5.71–100%), available phosphorus (1.4–31%), yields of various crops (4.78–25%), value of crop productivity (2.53%), net return (30%), and reductions in runoff (22%) and soil loss 64.9% (Table 5).

Other improvements observed include reductions in gulley head retreat rate (100%), runoff (11.11–55.56%), and number of destroyed dams (2.82%), due to interventions of subsurface geomembrane dams, check dams with vegetation and boulder-faced check dams, respectively (Table 5).

Table 4 Impact of water harvesting and production technologies

Interventions	Measured impact	Before intervention	After intervention	Percentage difference	Description of study setting	References
Micro-dam reservoirs (MDR)	Sediment deposition	0 t/ha	19 t/ha/year		Average value from 11 MDR	Tamene et al. (2006)
	Income		50% more income	50%	Irrigators compared with rainfed cultivators	Gebregziabher et al. (2009)
River diversion	Income		50 more income	50%	Irrigators compared with rainfed cultivators	Gebregziabher et al. (2009)
Ground water	Income		50% more income	50%	Irrigators compared with rainfed cultivators	Gebregziabher et al. (2009)
Catchment level water harvesting interventions	Runoff		43% reduction	−43%	Average value for two catchments	Grum et al. (2017b)
	Sediment deposition		54.5% reduction	−54.5%	Average value for two catchments	Grum et al. (2017b)
Roof water harvesting	Water harvested		5000 Lt per household		Harvested water in normal year, 2500 Lt in drier year	Helvetas (2017)
Spate irrigation	Wheat yield	4 ton/ha	13 ton/ha	225%	Yield compared with and without intervention	Van den ham (Ham 2008)
	Barley yield	7 ton/ha	12 ton/ha	71.4%	Yield compared with and without intervention	Ham (2008)
	Teff yield	3 ton/ha	6 ton/ha	100%	Yield compared with and without intervention	Ham (2008)
	Haricot bean yield	6 ton/ha	15 ton/ha	150%	Yield compared with and without intervention	Ham (2008)
	Maize yield	3 ton/ha	10 ton/ha	233.3%	Yield compared with and without intervention	Ham (2008)
Roadside water harvesting	Soil moisture content		100% increase	100%	Soil moisture around water harvesting trenches compared before and after intervention	Woldearegay et al. (2015)

Table 5 Impacts of soil and water conservation interventions

Intervention	Measured impact	Before	After	% change	Description of experimental settings	References
Stone bunds on hillside	Soil organic carbon	1.72%	2.34%	36.05%	Terraced hillsides compared with nonterraced hillsides	Hishe et al. (2017)
Stone bunds	Soil organic matter	2.01%	4.04%	100.99%	Terraced hillsides compared with nonterraced hillsides	Hishe et al. (2017)
	Soil organic carbon	0.63%	0.70%	11.11%	Terraced farmlands compared with nonterraced farmlands	Hishe et al. (2017)
	Soil organic matter	1.09%	1.20%	10.09%	Terraced farmlands compared with nonterraced farmlands	Hishe et al. (2017)
	Total nitrogen	0.05%	0.1%	100%	Terraced farmlands compared with nonterraced farmlands	Hishe et al. (2017)
	Total nitrogen	0.14%	0.19%	5.71%	Terraced hillsides compared with nonterraced hillsides	Hishe et al. (2017)
	Available phosphorus	0.71 ppm	0.72 ppm	1.40%	Terraced hillsides compared with nonterraced hillsides	Hishe et al. (2017)
	Available phosphorus	0.45 ppm	0.56 ppm	24.44%	Terraced farmlands compared with nonterraced farmlands	Hishe et al. (2017)
	Plant available phosphorus	10.69 mg/kg	14.07 mg/kg	31.61%	Soil in nonterraced land compared with soil in terrace bunches	Vagen et al. (1999)
	Reduced runoff	1.11	1.36	−22.52%	Interventions compared with untreated land, values are average for three land use types	Taye et al. (2013)
	Soil loss	57 t/ha/yr	20 t/ha/yr	−64.91%	Terraced farmland compared with nonterraced farmland	Gebremichael et al. (2005)
	Sediment deposition	–	59 t/ha/yr		Sediment deposition measured behind the stone bunds	Gebremichael et al. (2005)
	Sediment accumulation		58 t/ha/yr		An interdisciplinary comparison of terraced and nonterraced land	Nyssen et al. (2007)

	Cereal yields	632 kg/ha	683 kg/ha	8.07%	Terraced farmlands compared with nonterraced farmlands	Vancampenhout et al. (2006)
	Teff yield	501 kg/ha	556 kg/ha	10.98%	Terraced farmlands compared with nonterraced farmlands	Vancampenhout et al. (2006)
	Cicer arietinum yield	335 kg/ha	351 kg/ha	4.78%	Terraced farmlands compared with nonterraced farmlands	Vancampenhout et al. (2006)
	Grain yields	0.58 t/ha/yr	0.65 t/ha/yr	12.07%	An interdisciplinary comparison of terraced and nonterraced land	Nyssen et al. (2007)
	Value of crop productivity	1614 birr/ha	2026 birr/ha	25.53%	Terraced farmland yield compared with nonterraced one in a modeling study	Kassie et al. (2008)
	Net return over 30 year planning horizon		30% more	30%	Terraced farms compared with nonterraced ones	Gebremedhin et al. (1999)
Sub-surface geomembrane dam	Gulley head retreat rate	0.34 m/ year	0 m/year	100%	Treated area s head cut retreat compared with an average value from former study (Frankl et al. 2012)	Frankl et al. (2016)
Trenches		1.11	1.93	73.87%	Trenches compared with untreated land, values are average for three land use types	Taye et al. (2013)
Sandstone check dam with vegetation	Reduction in runoff discharge	18%	8%	−55.56%	Sandstone check dam without vegetation compared with the one with vegetation	Guyassa et al. (2017)
Limestone check dam with vegetation	Reduced runoff	9%	8%	−11.11	Limestone check dam without vegetation compared with the one with vegetation	Guyassa et al. (2017)
Boulder-faced log dams	Destroyed dams	39%	37.9%	−2.82%	Durability of boulder-faced log dams compared with that of looser rock check dams from another study (Nyssen et al. 2004b)	Nyssen et al. (2017)

Impact of Soil Fertility Improvement Interventions

The different soil fertility improvement interventions have resulted in various positive impacts. These include improved grain yields of 10.39–103.08% (use of compost), 63.7–71.99% (use of bioslurry), and 125.76% (use of reservoir sediment) (Table 6). The use of compost and bioslurry is not only a cheap source of fertilizers but also that their use helps in management and removal of domestic and farmland wastes, which would otherwise be source of health concerns in rural areas (Beyene 2011). Moreover, plants that are normally considered noxious weeds, such as *Parthenium hysterophorus*, *Datura stramonium,* and *Argemone mexicana,* have been have been used for composting resulting in both improved soil fertility while at the same time removing weeds (Tedla 2010).

Some EBA soil fertility management options may not be able to improve crop productivity as compared to the inorganic fertilizers, where crop yields have been observed to decline as inorganic fertilizers are replaced by composts (Table 6). However, even though inorganic fertilizers cause a boost in crop yields in the short term, their prolonged and intensive use causes decline of agro-biodiversity and over all soil and ecological health (Hadgu et al. 2009). Therefore, owing to the desirable long-term impacts they have, as compared to inorganic fertilizers, and the significant contribution in crop yields, there is a potential for the use of EBA practices in soil fertility improvement such as composting and bioslurry.

Impact of Integrated Watershed Management Interventions

Observed impacts of IWM interventions include reductions in: runoff (7.9–94%), erosion (89%), soil loss (32–37%), sediment yield (77%), and percentage bareland (75%) and increments in: sediment deposition (22.41%), percentage irrigated land (3077%), forest cover (142.3–202.4%), bush land (72%), and yield of various crops (60–100%) (Table 7). The runoff and erosion rates observed by the reviewed studies have shown a tremendous improvement from the 42 tons/ha that has been recorded before the start of the integrated watershed management interventions (Hurni 1988). Most of the positive improvements reported for northern Ethiopia are similar to the impacts of IWM reported elsewhere (Mekonen and Tesfahunegn 2011). A qualitative assessment by Michael and Waters-Bayer (2007) also reported similar observations of increased vegetation cover, more water infiltrated into the soil, reduced siltation, and increased crop yields. Generally speaking, because of the various integrated interventions, the effect of recurrent drought and extreme land degradation is effectively offset that the Tigray regional state is now more productive and greener than it used to be some 145 years ago (Nyssen et al. 2014).

Table 6 Impact of soil fertility improvement interventions

Intervention	Measured impact	Before treatment (kg/ha)	After treatment (kg/ha)	Percentage change	Description of study setting	References
Compost	Grain yield	1200	2437	103.08%	Farmlands with compost compared with untreated farmlands; results are 7 years' average for seven cereal crops	Edwards (2007a, b)
	Grain yield	1812	2437	34.49%	Farmlands with compost compared with farmlands treated with inorganic fertilizers; results are 7 years' average for seven cereal crops	Edwards (2007a, b)
	Teff yield	872	1113	27.63%	Compost applied at 6.4 t/ha/year compared with nonfertilized land	Tedla (2010)
	Barley yield	2173	2950	35.75%	Compost applied at 6.4 t/ha/ year compared with nonfertilized land	Tedla (2010)
	Faba bean yield	3334	4230	26.87%	Compost applied at 6.4 t/ha/ year compared with nonfertilized land	Tedla (2010)
	Faba bean yield	3832	4230	10.39%	Compost applied at 6.4 t/ha/ year compared with a land fertilized by inorganic fertilizer at standard rates	Tedla (2010)
	Teff yield	1120	1113	−0.625%	Compost applied at 6.4 t/ha/ year compared with a land fertilized by inorganic fertilizer at standard rates	Tedla (2010)
	Barley yield	3025	2950	−2.48%	Compost applied at 6.4 t/ha/ year compared with a land fertilized by inorganic fertilizer at standard rates	Tedla (2010)
	Straw yield	2477	4073	64.43%	Farmlands with compost compared with untreated farmlands; results are 7 years' average for seven cereal crops	Edwards (2007a, b)

(continued)

Table 6 (continued)

Intervention	Measured impact	Before treatment (kg/ha)	After treatment (kg/ha)	Percentage change	Description of study setting	References
Bioslurry	Wheat yield	1711	2800	63.70%	Bioslurry-fertilized land compared with nonfertilized land	Beyene (2011)
	Barley yield	1528	2628	71.99%	Bioslurry-fertilized land compared with nonfertilized land	Beyene (2011)
	Barley straw	2417	4056	67.81%	Bioslurry-fertilized land compared with nonfertilized land	Beyene (2011)
	Wheat yield	4607	2800	−39.22%	Bioslurry-fertilized land compared with land fertilized by in-organic fertilizer	Beyene (2011)
	Wheat straw	4707	4267	−9.35	Bioslurry-fertilized land compared with land fertilized by in-organic fertilizer	Beyene (2011)
	Wheat straw	3732	4267	14.34%	Bioslurry-fertilized land compared with nonfertilized land	Beyene (2011)
Fine reservoir sediment	Garlic yield	2721	6143	125.76%	Land fertilized with fine reservoir sediment applied at 15–30 cm deep compared with untreated land	Girmay et al. (2012)

Table 7 Impacts of integrated watershed management interventions

Measured impact	Before intervention	After intervention	Percentage change	Description of study	References
Runoff		27% reduction	−27%	A modeling study measuring changes before and after intervention	Haregeweyn et al. (2012)
Runoff from cultivated land	156.66	37.39	−76.13%	Measurement taken before and after intervention	Alem et al. (2015)
Runoff from Bushland	169.54 mm/year	156.01 mm/year	−7.98%	Measurement taken before and after intervention	Alem et al. (2015)
Runoff from bareland	188.40 mm/year	10.93 mm/year	−94.19%	Measurement taken before and after intervention	Alem et al. (2015)
Runoff from exclosure	188.40 mm/year	110.55 mm/year	−41.32%	Measurement taken before and after intervention	Alem et al. (2015)
Sheet and rill erosion		89% reduction	−89%	A modeling study measuring changes before and after intervention	Haregeweyn et al. (2012)
Soil loss by sheet and rill erosion		78% less	−78%	Sediment deposition measured at different conservation structure	Nyssen et al. (2008b)
Soil loss		32% reduction	−32%	Analysis of landscape photographs in 1975 and 2006	Munro et al. (2008)
Soil loss	14.3t/ha/yr	9 t/ha/yr	−37.06%	Land use and management were mapped and analyzed for 2000 and 2006	Nyssen et al. (2009)
Sediment deposition	5.8 t/ha/yr	7.1 t/ha/yr	22.41%	Land use and management were mapped and analyzed for 2000 and 2006	Nyssen et al. (2009)

(*continued*)

Table 7 (continued)

Measured impact	Before intervention	After intervention	Percentage change	Description of study	References
Sediment yield	8.5 t/ha/yr	1.9 t/ha/yr	−77.65%	Land use and management were mapped and analyzed for 2000 and 2006	Nyssen et al. (2009)
Area of irrigated land	7 ha	222.4 ha	3,077%	An analysis of aerial photograph in one watershed	Alemayehu et al. (2009)
Forest cover	32.4 ha	98 ha	202.4%	An analysis of aerial photograph in one watershed	Alemayehu et al. (2009)
Forestland	2.6%	6.3%	142.30%	Analysis of areal landscape photographs (1972, 1984/1986, and 2000)	Mûelenaere et al. (2014)
Bareland	32%	8%	−75%	Analysis of areal landscape photographs (1972, 1984/1986, and 2000),	Mûelenaere et al. (2014)
Bush land	25%	43%	72%	Analysis of areal landscape photographs (1972, 1984/1986 and 2000),	Mûelenaere et al. (2014)
Teff yield	0.3 t/ha	0.6 t/ha	100%	Yields compared between 1997 (before intervention) and 2004 (after intervention)	Alemayehu et al. (2009)
Wheat yield	0.5 t/ha	0.8 t/ha	60%	Yields compared between 1997 (before intervention) and 2004 (after intervention)	Alemayehu et al. (2009)
Barley yield	0.45 t/ha	0.75 t/ha	66.67%	Yields compared between 1997 (before intervention) and 2004 (after intervention)	Alemayehu et al. (2009)

Challenges with EBA Interventions and Future Directions

Though the changes brought about by the different EBA interventions are impressive and have been confirmed and reconfirmed by many studies, certain issues threaten the sustainability of the positive benefits of the interventions exist. The most important challenges include challenges of mobilizing public support, due to limited immediate economic benefits from interventions and a misguided approach for recruiting popular support and specific technical challenges with some interventions. While the challenge with the approach of recruiting popular support is explained below, specific technical challenges and recommended solutions are outlined in Table 8.

Challenges on Mobilizing Public Support

In a review of soil and water conservation interventions in Tigray, Gebremeskel et al. (2017) concluded that voluntary popular participation in the form of free labor days (mid to late 1980s) and then work for food program in the 1990s, accompanied by integration of disciplines (social, technical, and institutional) were most important reasons for the observed impressive success. Similarly, Nyssen et al. (2004a) indicated that farmers participate voluntarily, because in highly degraded areas like northern Ethiopia, farmers are left with no other alternatives, except improved land management or rehabilitation.

However, Segers et al. (2008a) argued that local farmers' mass participation is more of a support to the political agenda or conformity to popular practice than an understanding of or anticipation of the financial benefits to be accrued from participating in such schemes. In other words, it means that farmers accept interventions even knowing fully that they are not suitable for them, perhaps, why some very ambitious projects like the "*horeye*" water harvesting, despite obviously destined to fail, did not face any opposition by farmers. The Tigray regional administration was mainly successful in gaining popular support for its land rehabilitation projects by tapping into the common history and legacies of solidarity during the armed struggle of the Tigrian People's Liberation Front (TPLF) against the "*Dergue*" military regime, than by convincing farmers of the economic benefits of the projects (Segers et al. 2008a). It has been demonstrated earlier in this chapter, the number of studies that showed economic or livelihood benefits is also very limited (Fig. 5). This makes it difficult to make economic arguments for further dissemination of successful interventions. It is, however, also important to note that economic or livelihood benefits need time to manifest and that implementers need to subsidize farmers' efforts until economic incentives can attract voluntary local engagement (Gebremedhin et al. 1999). Secure land tenure rights can also reinforce private incentives to make long-term investments in soil conservation (Gebremedhin and Swinton 2003). Moreover, it is important to raise the Tigrean masses awareness that the interventions are ultimately meant to increase income and productivity, and are

Table 8 Main challenges of important EBA interventions in Tigray regional state and recommended solutions

Types of EBA interventions	Main drawbacks, limitations, challenges and side effects	Causes of problems	References	Proposed or Recommended solutions	References
All interventions	Failure to make economic arguments for the interventions	Most of the observed impacts need time to be translated into economic or livelihood benefits	Teshome et al. (2013)	Capitalizing on those interventions that would provide immediate capital return	Teshome et al. (2013)
Exclosures	Lack of economic incentives for farmers	In many places, procedures on economic utilization of grass and other biomass from exclosures not set	Gebremeskel et al. (2017)	Developing guidelines on grass sharing, seasonal grazing etc., expanding the practice of honey bee rearing in exclosures	Gebregziabher et al. (2017)
Exclosures	Complete exclusion of livestock may result in encroachment of invasive bushes and weeds	Because grazing provides services like breaking seed dormancy, nutrient cycling and removal of old outgrowth	Stavi et al. (2016)	Prescribed moderate grazing	Yayneshet et al. (2009)
Zero-grazing	Low level of adoption	Shortage of livestock feed, low level of awareness, culture of keeping large number of livestock; unprotected communal areas, limited water resources for forage development	Yami et al. (2011, Gebreyohannes and Hailemariam (2011)	Breed improvement accompanied by destocking, participation of local communities during planning and implementation	Yami et al. (2011, Gebreyohannes and Hailemariam (2011)
Tree plantation/ enrichment	The survival rate of seedlings very low	Lack of immediate benefits that make investment in tree nursing very limited: Wrong choice of tree species	Reubens et al. (2011, Aerts et al. (2007)	Improved nursing practices (watering, sheltering and improved planting conditions), providing incentives for tree grower: Identification and selection of drought tolerant high survival potential species	Reubens et al. (2011, Balehegn et al. (2015)

Agroforestry (trees on farm)	Tree shade crops, resource depletion, and barrier for cultivation	Failure to choose the right tree species for the right land, lack of knowledge tree management	Ernstberger (2017)	Awareness creation on the long term and short term benefits of agroforestry	
Silvopasture	Low level of adoption	Farm size, negative interaction, water scarcity, obstruction during plowing and incapability to fence tree seedlings	Hachoofwe (2012)	Choosing drought tolerant, multipurpose, adaptive and productive tree species	Balehegn (2017b), Balehegn et al. (2015)
Microdam reservoirs	Water leakage/seepage, insufficient inflow, structural damages, spillway erosion problems. siltation, lack of proper water management practices,	Insufficient or improper understanding of the geological and edaphic characteristics of sites before embarking on construction	Berhane et al. (2016a)	Undertaking detailed feasibility study for future construction. Installation of a cut-off wall at the upstream toe of the dam for those with leakage; utilization of the water from big diameter shallow hand dug wells from the leakage zone downstream	Berhane et al. (2016b)
	Eutrophication and a high occurrence of blooms of toxic *cyanobacteria*:		Dejenie et al. (2008)	Understanding the mechanisms of eutrophication for developing management options	Dejenie et al. (2008)
Check dams	Crop desiccation, collapse of dams, etc.	Soil piping	Frankl et al. (2016)	Application of Geomembrane dams	Frankl et al. (2016)
Gabion check dams	Gabion failure in ephemeral streams with coarse bed load, which abrades at the chute step: Reported problems of abrasion and collapse in torrents with coarse bed load and (2) the cost of gabion baskets	Abrasion of wires by bed-load movement over stepped chutes	Nyssen et al. (2017)	The use of boulder faced check dams in areas with strong streams	Nyssen et al. (2017)

(*continued*)

Table 8 (continued)

Types of EBA interventions	Main drawbacks, limitations, challenges and side effects	Causes of problems	References	Proposed or Recommended solutions	References
Horeye	Water seepage, inability to hold water, early dry up	Mostly abandoned because there was no consultation of farmers, pure top down approach	Segers et al. (2008a, b)	Developing construction guidelines relevant to specific topography, soil or geology. Implementing small scale water harvesting in consultation to users	Gebremeskel et al. (2017)
Shallow ground water irrigation	Well design and construction problems, high costs of pumps and oil, depletion of groundwater due to excessive withdrawal, emergence of conflicts due to competition for resources,	Lack of technical competence on the side of farmers and experts	Woldearegay and Van Steenbergen (2015)	Technical training and capacity building on site selection, construction and designing, management and utilization of water	Woldearegay and Van Steenbergen (2015)
Spate irrigation	Technical inefficiency and failures (e.g., huge amount of sediment deposition, salinity), significant water loss due to inefficient canal system, water resources conflicts	Limited technical competence, lack of involvement of beneficiaries at different states of projects	Hiben and Tesfa-alem (2014), Kidane (2009)	Development and dissemination of design guidelines and a manual, managing conflicts, following a participatory approach	Hiben and Tesfa-alem (2014)

Stone bunds/ terraces	Decline in effectiveness of sediment trapping, with time	With time, stone bunds are filled and reach the point where they no more prevent soil loss	Taye et al. (2015), Nyssen et al. (2007)	Periodic maintenance of bunds or implementing self-sustaining bunds that grow in height with time (e.g. cactus or other plant hedges)	Taye et al. (2015), Nefzaoui and El Mourid (2010)
	Harbors rodents causing crop damage	Porous designs serve as shelters for small rodents	Meheretu et al. (2014, 2015)	Developing a design that deters rodents e.g. integrating branches from spiny trees into the bund	Meheretu et al. (2014, 2015)
	Cost of building almost equal to the benefit induced by the increase in crop yield	Building is too labor intensive, especially where stone is not readily available	Nyssen et al. (2007, 2008b)	Current programs of food for work, safety net. In areas where farmers cannot see incentive in building stone bunds, government should subsize	Gebremedhin et al. (1999)
	Sometimes aggravates sheet and rill erosion on farms	In areas where stone is a limited resource, excessive removal of stone and gravel from farms causes sheet and rill erosion	Nyssen et al. (2007)	Utilizing alternative bund building materials, soil or vegetation bunds, transporting stone from other areas	
	Take land out of production	In low productive areas the increase in productivity or soil protection is offset by the land taken out of production	Nyssen et al. (2007)		
Bioslurry compost	Shortage of feed stock or dung	Most dung in rural areas is used as a fuel	Kelebe et al. (2017)	The use of alternative feed stock such as human excreta	Kelebe et al. (2017), Beyene (2011)

(*continued*)

Table 8 (continued)

Types of EBA interventions	Main drawbacks, limitations, challenges and side effects	Causes of problems	References	Proposed or Recommended solutions	References
Lose rock check dams	Frequent collapse, close to 39%	Technical inefficiencies in the construction	Nyssen et al. (2004b)	Development of technical construction guidelines for different types of geologic and edaphic formations, where catchment areas are large or there are steep slopes, repair dams as soon as partial collapse starts use biological gulley control methods	Nyssen et al. (2004b)
Small scale irrigation	Not adopted well	Myopic project planning, inadequate engineering studies, unsound designs, too short a time for implementation, and lack of full farmer involvement at different levels of project planning and implementation	Aberra (2004)	Participatory approaches to project planning, design and management. Skills training to farmers and technicians	Aberra (2004)
Roof top water harvesting	Not adopted well	Lack of knowledge base, technical skills, awareness and extension in urban areas	Biazin et al. (2012)	Awareness creation on the technology, provision of training and technical skills building	Biazin et al. (2012)

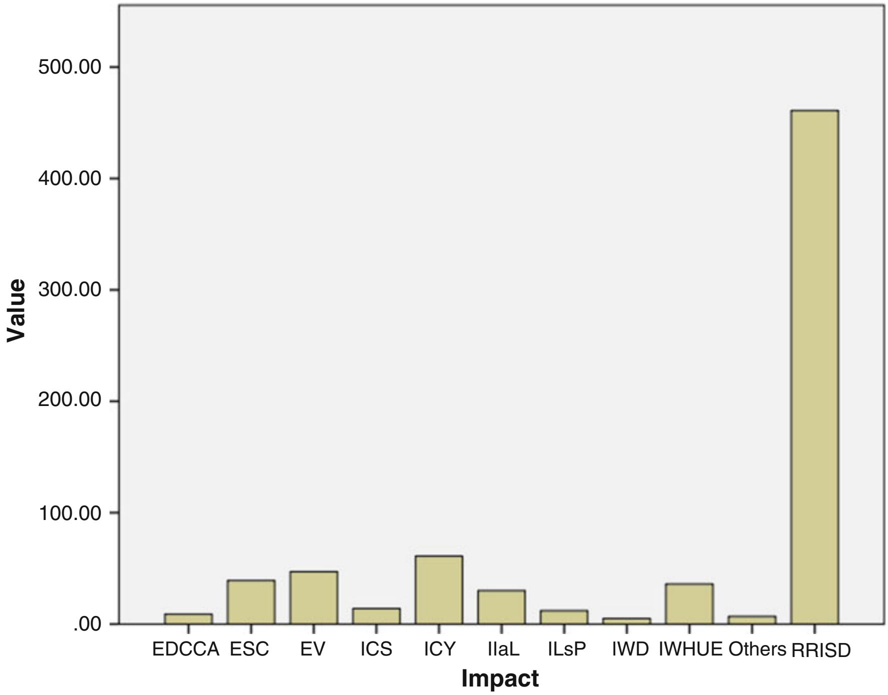

Fig. 5 Number of cases of evidences for different positive impacts. *EDCCA* Enhanced drought and climate change adaptation, *ESC* Enhanced soil characteristics, *EV* Enhanced vegetation, *ICS* Improved carbon stocks, *ICY* Improved crop yields, *IIaL* Improved income and livelihoods, *ILsP* Improved livestock productivity, *IWD* Improved wildlife diversity, *IWHUE* Improved water harvesting and use efficiency, *RRISD* Reduced runoff and increased sediment deposition

not orders that they have to blindly follow, as such a thinking would improve the household level adoption of these technologies, which is currently either lacking or very limited (Segers et al. 2008a).

Conclusion

In this chapter, we critically reviewed studies on decades of extensive EBA adaptation practices, implemented in one of, hitherto, the most ecologically fragile, hunger, and poverty-ridden corners of the world that has been repeatedly plagued by recurrent drought and extreme weather variability. The review includes 170 publications on 30 different types of EBA interventions in 400 sites in Tigray. Reviewed studies indicated that Tigrian farmers, together with the Tigray State Government of Ethiopia, their donors and development partners have demonstrated that through dedicated, evidence-based interventions, it is not only possible to beat the problems of land degradation, recurrent drought, extreme weather variability but also turn around the challenges and convert land into highly stable productive ecosystems.

Interventions spanned variety of simple, low cost, locally available ecosystem-based adaptation interventions that can generally fall into six categories, namely, biological rehabilitation, conservation agriculture, integrated watershed management, soil fertility improvement, soil and water conservation, and water harvesting and production interventions. Quantified and reported impacts of the EBA included in general, improvement in biophysical ecological variables such as reduced runoff, increased soil deposition, improved vegetation cover etc., (63.93% of cases), improvements in crop (8.46% of cases), improvement in livestock yields (1.6% of cases), and income/livelihoods (4.16% of cases).

Despite wide spread reported improvement in biophysical variables such as reduced runoff, reduced soil erosion, improved soil fertility, etc., improvement in income or livelihoods has only been reported 4.16% of cases. This is probably caused by methodological difficulty for quantifying economic or livelihood impacts, which in turn limits the ability to make livelihood or economic argument for promoting the different EBA interventions. Therefore, there is a need for developing tools that enable the generation of evidence on economic impact of interventions and capitalizing on EBA interventions that would enable the maximum economic or livelihoods benefits to local farmers.

While popular participation has been repeatedly cited as an important reason for successful implementation of the EBA interventions, household level or private adoption of the interventions still remains very limited. Almost all practices are implemented in communal or government land. This puts a question as to the motive of farmers in participating in the implementation of interventions. Though, many indicated that farmers participate voluntarily, by sometimes offering free labor days, there is evidence that this is mainly behavior of conformity, rather than a need-based voluntary involvement. This might explain why most of the interventions are lacking from private land or household-based interventions. This is important because, without popular household-based adoption, the sustainability of the interventions could be under question. Therefore, it is important to raise awareness on the short and long term economic or livelihood benefits of the EBA interventions, so that individual farmers can adopt them.

Finally, the types of EBA and land rehabilitation interventions, challenges faced and solutions implemented give important lessons for replicating the success in northern Ethiopia to similar places elsewhere, with similar challenges.

Cross-References

- ► Area Exclosure as a Strategy for Climate Change Mitigation: Case Study From Tigray Region, Northern Ethiopia
- ► Building Resilience to Climate Change: Water Stewardship in Rainfed Agrarian Villages in Maharashtra, India
- ► Climate Change, Vulnerability, and Adaption Under the Small Farming Households of Konso Community, Southern Ethiopia

- ▶ Ecosystem-Based Adaptation and Gender Perspectives From a Participatory Vulnerability Assessment in Mountainous Rural Vietnam
- ▶ Effect of Mulching on Soil Temperature and Moisture for Potato Production in Agro-Ecological Zones of Central Highlands of Kenya
- ▶ Environmental Sustainability and Systems Thinking: A Foundation for More Effective Climate Policy
- ▶ Fertilization Strategies Based on Climate Information to Enhance Food Security Through Improved Dryland Cereals Production
- ▶ Forest Cover Change and Its Impacts on Ecosystem Services in Katimok Forest Reserve, Baringo County, Kenya
- ▶ Resilience in Climate Stressed Environment Through Water Grabbing
- ▶ Water Harvesting Technology for Enhancing Food Security Livelihood: The Case of Northern Katsina State, Nigeria
- ▶ Water Management as a Means for Climate Change Adaptation and Sustainable Development

References

Aberra Y (2004) Problems of the solution: intervention into small-scale irrigation for drought proofing in the Mekele Plateau of northern Ethiopia. Geogr J 170:226–237

Abesha GA (2014) Herbaceous vegetation restoration potential and soil physical condition in a mountain grazing land of eastern Tigray, Ethiopia. J Agric Environ Int Dev (JAEID) 108:81–106

Aerts R, Negussie A, Maes W, November E, Hermy M, Muys B (2007) Restoration of dry Afromontane Forest using pioneer shrubs as nurse-plants for *Olea europaea* ssp. *cuspidata*. Restor Ecol 15:129–138

Aerts R, Lerouge F, November E, Lens L, Hermy M, Muys B (2008) Land rehabilitation and the conservation of birds in a degraded Afromontane landscape in northern Ethiopia. Biodivers Conserv 17:53–69

Aerts R, Nyssen J, Haile M (2009) On the difference between "exclosures" and "enclosures" in ecology and the environment. J Arid Environ 73:762–763

Alem T, Tsegazeab G, Micheale G, Atinkut M (2015) Characterization and impact assessment of water harvesting techniques: a case study of Abreha Weatsbeha watershed, Tigray, Ethiopia. Department of Land Resources Management and Environmental Protection, Mekelle University, Ethiopia

Alemayehu F, Taha N, Nyssen J, Girma A, Zenebe A, Behailu M, Deckers S, Poesen J (2009) The impacts of watershed management on land use and land cover dynamics in eastern Tigray (Ethiopia). Resour Conserv Recycl 53:192–198

Araya A, Stroosnijder L (2010) Effects of tied ridges and mulch on barley (*Hordeum vulgare*) rainwater use efficiency and production in northern Ethiopia. Agric Water Manag 97:841–847

Araya T, Cornelis W, Nyssen J, Govaerts B, Bauer H, Gebreegziabher T, Oicha T, Raes D, Sayre KD, Haile M (2011) Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, northern Ethiopia. Soil Use Manag 27:404–414

Araya T, Nyssen J, Govaerts B, Baudron F, Carpentier L, Bauer H, Lanckriet S, Deckers JA, Cornelis W (2016a) Restoring cropland productivity and profitability in northern Ethiopian drylands after nine years of resource-conserving agriculture. Exp Agric 52:165–187

Araya T, Nyssen J, Govaerts B, Deckers JA, Sommer R, Bauer H, Gebrehiwot K, Cornelis W (2016b) Seven years resource-conserving agriculture effect on soil quality and crop productivity in the Ethiopian drylands. Soil Tillage Res 163:99–109

Asres HG (2012) Effect of exclosure on environment and its socio economic contributions to local people: in the case study of halla exclosure, Tigray, Ethiopia. Norwegian University of Life Sciences, Ås

Awulachew SB, Merrey D, Kamara A, van Koppen B, Penning de Vries F, Boelee E (2005) Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia. IWMI, Colombo, Sri Lanka

Babulo B, Muys B, Nega F, Tollens E, Nyssen J, Deckers J, Mathijs E (2009) The economic contribution of forest resource use to rural livelihoods in Tigray, northern Ethiopia. Forest Policy Econ 11:109–117

Balana BB, Mathijs E, Muys B (2010) Assessing the sustainability of forest management: an application of multi-criteria decision analysis to community forests in northern Ethiopia. J Environ Manag 91:1294–1304

Balehegn M (2017a) Increased publication in predatory journals by developing countries' institutions: what it entails? And what can be done? Int Inf Libr Rev 49:97–100

Balehegn M (2017b) Silvopasture using indigenous fodder trees and shrubs: the underexploited synergy between climate change adaptation and mitigation in the livestock sector. In: Leal Filho W, Belay S, Kalangu J, Menas W, Munishi P, Musiyiwa K (eds) Climate change adaptation in Africa: fostering resilience and capacity to adapt. Springer International Publishing, Cham

Balehegn M, Eik L, Tesfay Y (2014) Replacing commercial concentrate by *Ficus thonningii* improved productivity of goats in Ethiopia. Trop Anim Health Prod:1–6

Balehegn M, Eik LO, Tesfay Y (2015) Silvopastoral system based on *Ficus thonningii* : an adaptation to climate change in northern Ethiopia. Afr J Range Forage Sci 32:183–191

Berhane G, Gebreyohannes T, Martens K, Walraevens K (2016a) Overview of micro-dam reservoirs (MDR) in Tigray (northern Ethiopia): challenges and benefits. J Afr Earth Sci 123:210–222

Berhane G, Kebede S, Gebreyohannes T, Martens K, van Camp M, Walraevens K (2016b) An integrated approach for detection and delineation of leakage path from Micro-Dam Reservoir (MDR): a case study from Arato MDR, northern Ethiopia. Bull Eng Geol Environ 75:193–210

Bewket W (2007) Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: acceptance and adoption by farmers. Land Use Policy 24:404–416

Beyene G (2011) Bio-slurry – is it a fertilizer in the Making? SNV Netherlands Development Organisation http://www.snv.org/public/cms/sites/default/files/explore/download/et_bioslurry_-_is_it_a_fertiliser_in_the_making.pdf

Biazin B, Sterk G, Temesgen M, Abdulkedir A, Stroosnijder L (2012) Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa – a review. Phys Chem Earth 47/48:139–151

Birhane E, Gebremedihin KM, Tadesse T, Hailemariam M, Solomon N (2017) Exclosures restored the density and root colonization of arbuscular mycorrhizal fungi in Tigray, northern Ethiopia. Ecol Process 6:33

Brhane G, Wortmann CS, Mamo M, Gebrekidan H, Belay A (2006) Micro-basin tillage for grain sorghum production in semiarid areas of northern Ethiopia. Agron J 98:124–128

Conway D (2000) Some aspects of climate variability in the north east Ethiopian highlands-Wollo and Tigray. SINET: Ethiop J Sci 23:139–161

CSA (2010) The 2007 population and housing census of Ethiopia

Dejenie T, Asmelash T, de Meester L, Mulugeta A, Gebrekidan A, Risch S, Pals A, van der Gucht K, Vyverman W, Nyssen J (2008) Limnological and ecological characteristics of tropical highland reservoirs in Tigray, northern Ethiopia. Hydrobiologia 610:193–209

Descheemaeker K, Muys B, Nyssen J, Poesen J, Raes D, Haile M, Deckers JA (2006) Litter production and organic matter accumulation in exclosures of the Tigray highlands, Ethiopia. For Ecol Manag 233:21–35

Descheemaeker K, Muys B, Nyssen J, Sauwens W, Haile M, Poesen J, Raes D, Deckers JA (2009a) Humus form development during forest restoration in exclosures of the Tigray highlands, northern Ethiopia. Restor Ecol 17:280–289

Descheemaeker K, Raes D, Nyssen J, Poesen J, Haile M, Deckers JA (2009b) Changes in water flows and water productivity upon vegetation regeneration on degraded hillslopes in northern Ethiopia: a water balance modelling exercise. Rangel J 31:237–249

Descheemaeker K, Mapedza E, Amede T, Ayalneh W (2010) Effects of integrated watershed management on livestock-water productivity in water scarce areas in Ethiopia. Phys Chem Earth 35:723–729

Doswald N, Munroe R, Roe D, Giuliani A, Castelli I, Stephens J, Möller I, Spencer T, Vira B, Reid H (2014) Effectiveness of ecosystem-based approaches for adaptation: review of the evidence-base. Climate Dev 6:185–201

Edwards S (2007a) The impact of compost use on crop yields in Tigray, Ethiopia. Institute for Sustainable Development (ISD). In the proceedings of the international conference on organic agriculture and food security. FAO, Rome. Obtainable at: ftp://ftp.fao.org/paia/organicag/ofs/02-Edwards. pdf

Edwards S (2007b) Role of organic agriculture in preventing and reversing land degradation. In: Climate and land degradation. Springer, Berlin

Edwards MS (2012) Biogas-bioslurry: a package for narrowing gender disparity in the rural households-the case of Hintalo Wajirat and Ofla Woredas, Tigray Region

Ernstberger J (2017) Perceived multifunctionality of agroforestry trees in northern Ethiopia. MSc.: A case study of the perceived functions and associated personal values of trees for farming households in Tigray. Thesis. Swedish University of Agricultural Sciences. Alnarp, Sweden.

Frankl A, Poesen J, Deckers J, Haile M, Nyssen J (2012) Gully head retreat rates in the semi-arid highlands of northern Ethiopia. Geomorphology 173:185–195

Frankl A, Deckers J, Moulaert L, van Damme A, Haile M, Poesen J, Nyssen J (2016) Integrated solutions for combating gully erosion in areas prone to soil piping: innovations from the drylands of northern Ethiopia. Land Degrad Dev 27:1797–1804

Gebreegziabher T, Nyssen J, Govaerts B, Getnet F, Behailu M, Haile M, Deckers J (2009) Contour furrows for in situ soil and water conservation, Tigray, northern Ethiopia. Soil Tillage Res 103:257–264

Gebregziabher G, Namara RE, Holden ST (2009) Poverty reduction with irrigation investment: an empirical case study from Tigray, Ethiopia. Agric Water Manag 96:1837–1843

Gebregziabher D, Soltani A, Hofstad O (2017) Equity in the distribution of values of outputs from exclosures in Tigray, Ethiopia. J Arid Environ 146:75–85

Gebremedhin B, Swinton SM (2003) Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. Agric Econ 29:69–84

Gebremedhin B, Swinton SM, Tilahun Y (1999) Effects of stone terraces on crop yields and farm profitability: results of on-farm research in Tigray, northern Ethiopia. J Soil Water Conserv 54:568–573

Gebremedhin B, Pender J, Tesfay G (2004) Collective action for grazing land management in crop–livestock mixed systems in the highlands of northern Ethiopia. Agric Syst 82:273–290

Gebremeskel G, Gebremicael T, Girmay A (2017) Economic and environmental rehabilitation through soil and water conservation, the case of Tigray in northern Ethiopia. J Arid Environ 151:113–124

Gebremichael D, Nyssen J, Poesen J, Deckers J, Haile M, Govers G, Moeyersons J (2005) Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray highlands, northern Ethiopia. Soil Use Manag 21:287–297

Gebreyohannes G, Hailemariam G (2011) Challenges, opportunities and available good practices related to zero grazing in Tigray and Hararghe, Ethiopia. Drylands Coordination Group (DCG) Report

Gelaw AM, Singh B, Lal R (2014) Soil organic carbon and total nitrogen stocks under different land uses in a semi-arid watershed in Tigray, northern Ethiopia. Agric Ecosyst Environ 188:256–263

Gelaw AM, Singh B, Lal R (2015a) Organic carbon and nitrogen associated with soil aggregates and particle sizes under different land uses in Tigray, northern Ethiopia. Land Degrad Dev 26:690–700

Gelaw AM, Singh BR, Lal R (2015b) Soil quality indices for evaluating smallholder agricultural land uses in northern Ethiopia. Sustainability 7:2322–2337

Girmay G, Singh BR (2012) Changes in soil organic carbon stocks and soil quality: land-use system effects in northern Ethiopia. Acta Agric Scand Sect B Soil Plant Sci 62:519–530

Girmay G, Singh B, Nyssen J, Borrosen T (2009) Runoff and sediment-associated nutrient losses under different land uses in Tigray, northern Ethiopia. J Hydrol 376:70–80

Girmay G, Nyssen J, Poesen J, Bauer H, Merckx R, Haile M, Deckers J (2012) Land reclamation using reservoir sediments in Tigray, northern Ethiopia. Soil Use Manag 28:113–119

Grum B, Assefa D, Hessel R, Woldearegay K, Kessler A, Ritsema C, Geissen V (2017a) Effect of in situ water harvesting techniques on soil and nutrient losses in semi-arid northern Ethiopia. Land Degrad Dev 28:1016–1027

Grum B, Woldearegay K, Hessel R, Baartman JE, Abdulkadir M, Yazew E, Kessler A, Ritsema CJ, Geissen V (2017b) Assessing the effect of water harvesting techniques on event-based hydrological responses and sediment yield at a catchment scale in northern Ethiopia using the Limburg Soil Erosion Model (LISEM). Catena 159:20–34

Guyassa E, Frankl A, Zenebe A, Poesen J, Nyssen J (2017) Effects of check dams on runoff characteristics along gully reaches, the case of northern Ethiopia. J Hydrol 545:299–309

Hachoofwe EM (2012) Local ecological knowledge of trees on farms, constraints and opportunities for further integration in Tigray Region, northern Ethiopia: a case study of smallholder farmers in Abreha Wa Atsbeha and Adi gudom. Bangor University

Hadgu KM, Rossing WAH, Kooistra L, van Bruggen AHC (2009) Spatial variation in biodiversity, soil degradation and productivity in agricultural landscapes in the highlands of Tigray, northern Ethiopia. Food Sec 1:83–97

Hagos F, Pender J, Gebreselassie N (1999) Land degradation in the highlands of Tigray and strategies for sustainable land management. International Livestock Research Institute, Addis Ababa

Hagos EY, Schultz B, Depeweg H (2016) Reservoir operation in view of effective utilization of limited water in semi-arid areas the case of Gumsalasa earthen dam irrigation scheme in Tigray, Ethiopia. Irrig Drain 65:294–307

Ham J (2008) Dodota Spate irrigation system Ethiopia: a case study of Spate irrigation management and livelihood options

Haregeweyn N, Poesen J, Deckers JA, Nyssen J, Haile M, Govers G, Verstraeten G, Moeyersons J (2008a) Sediment-bound nutrient export from micro-dam catchments in northern Ethiopia. Land Degrad Dev 19:136–152

Haregeweyn N, Poesen J, Nyssen J, Govers G, Verstraeten G, de Vente J, Deckers J, Moeyersons J, Haile M (2008b) Sediment yield variability in northern Ethiopia: a quantitative analysis of its controlling factors. Catena 75:65–76

Haregeweyn N, Berhe A, Tsunekawa A, Tsubo M, Meshesha DT (2012) Integrated watershed management as an effective approach to curb land degradation: a case study of the Enabered watershed in northern Ethiopia. Environ Manag 50:1219–1233

Haregeweyn N, Tsunekawa A, Nyssen J, Poesen J, Tsubo M, Meshesha DT, Schutt B, Adgo E, Tegegne F (2015) Soil erosion and conservation in Ethiopia a review. Prog Phys Geogr 39:750–774

HELVETAS (2017) Rural roof water harvesting initiative in Tigray [Online]. Available: https://ethiopia.helvetas.org/en/projects/rrwhi/. Accessed 10 Jan 2017

Hengsdijk H, Meijerink GW, Mosugu ME (2005) Modeling the effect of three soil and water conservation practices in Tigray, Ethiopia. Agric Ecosyst Environ 105:29–40

Hiben MG, Tesfa-Alem G (2014) Spate irrigation in Tigray: the challenges and suggested ways to overcome them. In: Flood-based Farming for food security and adaption to climate change in Ethiopia: potential and challenges, International Water Management Institute (IWMI). Colombo, Sri Lanka, pp 137–148

Hishe S, Lyimo J, Bewket W (2017) Soil and water conservation effects on soil properties in the middle Silluh Valley, northern Ethiopia. Int Soil Water Conserv Res 5:231–240
Hurni H (1988) Degradation and conservation of the resources in the Ethiopian highlands. Mt Res Dev 8:123–130
Kassie M, Pender J, Yesuf M, Kohlin G, Bluffstone R, Mulugeta E (2008) Estimating returns to soil conservation adoption in the northern Ethiopian highlands. Agric Econ 38:213–232
Kelebe HE, Ayimut KM, Berhe GH, Hintsa K (2017) Determinants for adoption decision of small scale biogas technology by rural households in Tigray, Ethiopia. Energy Econ 66:272–278
Kidane H (2009) Community spate irrigation in Raya Valley: the case of three spate irrigation systems. Master's thesis, Addis Ababa University, Addis Ababa, Ethiopia
Lemenih M, Kassa H, Ababa A (2014) Re-greening Ethiopia: history, challenges and lessons. Forests 5:1896–1909
Mchugh OV, Steenhuis TS, Abebe B, Fernandes EC (2007) Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone north Wello zone of the Ethiopian highlands. Soil Tillage Res 97:19–36
Meaza H, Tsegaye D, Nyssen J (2016) Allocation of degraded hillsides to landless farmers and improved livelihoods in Tigray, Ethiopia. Norsk Geografisk Tidsskrift-norwegian J Geogr 70:1–12
Meheretu Y, Sluydts V, Welegerima K, Bauer H, Teferi M, Yirga G, Mulungu L, Haile M, Nyssen J, Deckers J (2014) Rodent abundance, stone bund density and its effects on crop damage in the Tigray highlands, Ethiopia. Crop Prot 55:61–67
Meheretu Y, Welegerima K, Sluydts V, Bauer H, Gebrehiwot K, Deckers J, Makundi R, Leirs H (2015) Reproduction and survival of rodents in crop fields: the effects of rainfall, crop stage and stone-bund density. Wildl Res 42:158–164
Mekonen K, Tesfahunegn GB (2011) Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia. Maejo Int J Sci Technol 5:312–330
Mekonnen M, Keesstra S, Baartman J, Ritsema C, Melesse A (2015) Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia. Cuadernos de Investigación Geográfica 41:7–22
Mekuria W, Veldkamp E (2012) Restoration of native vegetation following exclosure establishment on communal grazing lands in Tigray, Ethiopia. Appl Veg Sci 15:71–83
Mekuria W, Veldkamp E, Haile M, Nyssen J, Muys B, Gebrehiwot K (2007) Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. J Arid Environ 69:270–284
Mekuria W, Veldkamp E, Tilahun M, Olschewski R (2011) Economic valuation of land restoration: the case of exclosures established on communal grazing lands in Tigray, Ethiopia. Land Degrad Dev 22:334–344
Mekuria W, Langan S, Noble A, Johnston R (2017) Soil restoration after seven years of exclosure management in northwestern Ethiopia. Land Degrad Dev 28:1287–1297
Meshesha DT, Tsunekawa A, Tsubo M (2012) Continuing land degradation: cause–effect in Ethiopia's Central Rift Valley. Land Degrad Dev 23:130–143
Michael YG, Waters-Bayer A (2007) Trees are our backbone: integrating environment and local development in Tigray region of Ethiopia. Iied, London
Mûelenaere S, Frankl A, Haile M, Poesen J, Deckers J, Munro N, Veraverbeke S, Nyssen J (2014) Historical landscape photographs for calibration of Landsat land use/cover in the northern Ethiopian highlands. Land Degrad Dev 25:319–335
Munang R, Thiaw I, Alverson K, Mumba M, Liu J, Rivington M (2013) Climate change and ecosystem-based adaptation: a new pragmatic approach to buffering climate change impacts. Curr Opin Environ Sustain 5:67–71
Munro RN, Deckers J, Haile M, Grove A, Poesen J, Nyssen J (2008) Soil landscapes, land cover change and erosion features of the Central Plateau region of Tigrai, Ethiopia: photo-monitoring with an interval of 30 years. Catena 75:55–64
Nefzaoui A, El Mourid M (2010) Cactus pear for soil and water conservation in arid and semi-arid lands. In: Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa, Cactus Net Newsletter. Mekelle, Ethiopia p 117–126

Noulekoun F, Birhane E, Chude S, Zenebe A (2017) Characterization of *Faidherbia albida* (Del.) A. Chev. population in agroforestry parklands in the highlands of northern Ethiopia: impact of conservation, environmental factors and human disturbances. Agrofor Syst 91:123–135

Nyssen J, Haile M, Moeyersons J, Poesen J, Deckers JA (2000) Soil and water conservation in Tigray (northern Ethiopia): the traditional daget technique and its integration with introduced techniques. Land Degrad Dev 11:199–208

Nyssen J, Haile M, Moeyersons J, Poesen J, Deckers J (2004a) Environmental policy in Ethiopia: a rejoinder to Keeley and Scoones. J Mod Afr Stud 42:137–147

Nyssen J, Veyretpicot M, Poesen J, Moeyersons J, Haile M, Deckers JA, Govers G (2004b) The effectiveness of loose rock check dams for gully control in Tigray, northern Ethiopia. Soil Use Manag 20:55–64

Nyssen J, Poesen J, Gebremichael D, Vancampenhout K, Daes M, Yihdego G, Govers G, Leirs H, Moeyersons J, Naudts J (2007) Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in northern Ethiopia. Soil Tillage Res 94:151–163

Nyssen J, Naudts J, de Geyndt K, Haile M, Poesen J, Moeyersons J, Deckers J (2008a) Soils and land use in the Tigray highlands (northern Ethiopia). Land Degrad Dev 19:257–274

Nyssen J, Poesen J, Moeyersons J, Haile M, Deckers J (2008b) Dynamics of soil erosion rates and controlling factors in the northern Ethiopian highlands–towards a sediment budget. Earth Surf Process Landf 33:695–711

Nyssen J, Clymans W, Poesen J, Vandecasteele I, de Baets S, Haregeweyn N, Naudts J, Hadera A, Moeyersons J, Haile M (2009) How soil conservation affects the catchment sediment budget–a comprehensive study in the north Ethiopian highlands. Earth Surf Process Landf 34:1216–1233

Nyssen J, Govaerts B, Araya T, Cornelis WM, Bauer H, Haile M, Sayre K, Deckers J (2010) The use of the marasha ard plough for conservation agriculture in Northern Ethiopia. Agron Sustain Dev 31:287–297

Nyssen J, Frankl A, Haile M, Hurni H, Descheemaeker K, Crummey D, Ritler A, Portner B, Nievergelt B, Moeyersons J (2014) Environmental conditions and human drivers for changes to north Ethiopian mountain landscapes over 145years. Sci Total Environ 485:164–179

Nyssen J, Gebreselassie S, Assefa R, Deckers JA, Zenebe A, Poesen J, Frankl A (2017) Boulder-faced log dams as an alternative for gabion check dams in first-order ephemeral streams with coarse bed load in Ethiopia. J Hydraul Eng 143:05016005

Pender J, Gebremedhin B (2007) Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. J Afr Econ 17:395–450

Reubens B, Moeremans C, Poesen J, Nyssen J, Tewoldeberhan S, Franzel S, Deckers J, Orwa C, Muys B (2011) Tree species selection for land rehabilitation in Ethiopia: from fragmented knowledge to an integrated multi-criteria decision approach. Agrofor Syst:1–28

Rimhanen K, Ketoja E, Yli-Halla M, Kahiluoto H (2016) Ethiopian agriculture has greater potential for carbon sequestration than previously estimated. Glob Chang Biol 22:3739–3749

Segers K, Dessein J, Hagberg S, Develtere P, Haile M, Deckers J (2008a) Be like bees–the politics of mobilizing farmers for development in Tigray, Ethiopia. Afr Aff 108:91–109

Segers K, Dessein J, Nyssen J, Haile M, Deckers J (2008b) Developers and farmers intertwining interventions: the case of rainwater harvesting and food-for-work in Degua Temben, Tigray, Ethiopia. Int J Agric Sustain 6:173–182

Solomon N, Birhane E, Tadesse T, Treydte AC, Meles K (2017) Carbon stocks and sequestration potential of dry forests under community management in Tigray, Ethiopia. Ecol Process 6:20

Stavi I, Argaman E, Zaady E (2016) Positive impact of moderate stubble grazing on soil quality and organic carbon pool in dryland wheat agro-pastoral systems. Catena 146:94–99

Taddese G (2001) Land degradation: a challenge to Ethiopia. Environ Manag 27:815–824

Tamene L, Park SJ, Dikau R, Vlek PLG (2006) Reservoir siltation in the semi-arid highlands of northern Ethiopia: sediment yield–catchment area relationship and a semi-quantitative approach for predicting sediment yield. Earth Surf Process Landf 31:1364–1383

Taye G, Poesen J, Wesemael BV, Vanmaercke M, Teka D, Deckers J, Goosse T, Maetens W, Nyssen J, Hallet V (2013) Effects of land use, slope gradient, and soil and water conservation structures on runoff and soil loss in semi-arid northern Ethiopia. Phys Geogr 34:236–259

Taye G, Poesen J, Vanwesemael B, Vanmaercke M, Teka D, Deckers J, Goosse T, Maetens W, Nyssen J, Hallet V (2014) Effectiveness of soil and water conservation structures in reducing runoff and soil loss for different land use and slope gradients: case study from northern Ethiopia. EGU General Assembly conference abstracts

Taye G, Poesen J, Vanmaercke M, van Wesemael B, Martens L, Teka D, Nyssen J, Deckers J, Vanacker V, Haregeweyn N (2015) Evolution of the effectiveness of stone bunds and trenches in reducing runoff and soil loss in the semi-arid Ethiopian highlands. Z Geomorphol 59:477–493

Tedla HA (2010) The effect of compost on soil fertility enhancement and yield increment under smallholder farming: a case of Tahtai Maichew District-Tigray Region, Ethiopia. Inst. für Bodenkunde und Standortslehre, Stuttgart

Teklay A (2011) Seasonal availability of common bee flora in relation to land use and colony performance in Gergera Watershed Atsbi Wemberta District, Eastern Zone of Tigray, Ethiopia. MSc Thesis, Hawassa University, Hawassa, Ethiopia

Tesfahunegn GB (2015) Short-term effects of tillage practices on soil properties under Tef [Eragrostis tef (Zucc. Trotter)] crop in northern Ethiopia. Agric Water Manag 148:241–249

Teshome A, Rolker D, de Graaff J (2013) Financial viability of soil and water conservation technologies in northwestern Ethiopian highlands. Appl Geogr 37:139–149

Tetemke BA, Gebremeskel D, Takenaka K (2017) Ecological networking to scale-up and sustain ecological restoration in the dry lands of northern Ethiopia. 日本森林学会大会発表データベース 第 128 回日本森林学会大会. 日本森林学会, 819

Tilahun M, Muys B, Mathijs E, Kleinn C, Olschewski R, Gebrehiwot K (2011) Frankincense yield assessment and modeling in closed and grazed *Boswellia papyrifera* woodlands of Tigray, northern Ethiopia. J Arid Environ 75:695–702

Vagen T, Tilahun Y, Esser K (1999) Effects of stone terracing on available phosphorus and yields on highly eroded slopes in Tigray, Ethiopia. J Sustain Agric 15:61–74

Vancampenhout K, Nyssen J, Gebremichael D, Deckers JA, Poesen J, HAILE M, Moeyersons J (2006) Stone bunds for soil conservation in the northern Ethiopian highlands: impacts on soil fertility and crop yield. Soil Tillage Res 90:1–15

Waktola DK (2007) Rainwater harvesting in Ethiopia: capturing realities and harnessing opportunities. Rainwater Urban Design 2007:484

Woldearegay K, van Steenbergen F (2015) Shallow groundwater irrigation in Tigray, northern Ethiopia: practices and issues. In: Lollino G, Arattano M, Rinaldi M, Giustolisi O, Marechal J-C, Grant GE (eds) Engineering geology for society and territory - volume 3: river basins, reservoir sedimentation and water resources. Springer International Publishing, Cham

Woldearegay K, van Steenbergen F, Perez MA, Grum B, van Beusekom M (2015) Water harvesting from roads: climate resilience in Tigray, Ethiopia. IRF Examiner. 12 (Winter 2017): 1–7

Yami M, Gebrehiwot K, Stien M, Mekuria W (2007) Impact of area enclosures on density and diversity of large wild mammals: the case of May Ba'ati, Douga Tembien district, Central Tigray, Ethiopia. East Afr J Sci 1:55–68

Yami M, Vogl C, Hauser M (2011) Informal institutions as mechanisms to address challenges in communal grazing land management in Tigray, Ethiopia. Int J Sustain Dev World Ecol 18:78–87

Yami M, Mekuria W, Hauser M (2013) The effectiveness of village bylaws in sustainable management of community-managed exclosures in northern Ethiopia. Sustain Sci 8:73–86

Yayneshet T, Eik LO, Moe SR (2008) Feeding *Acacia etbaica* and *Dichrostachys cinerea* fruits to smallholder goats in northern Ethiopia improves their performance during the dry season. Livest Sci 119:31–41

Yayneshet T, Eik LO, Moe SR (2009) The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia. J Arid Environ 73:542–549

Yazew E (2015) Flood-based farming and the second five years growth and transformation plan of Tigray. Mekelle University, Mekelle, Tigray, Ethiopia