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Impacts of Soil and Water Conservation Practices on Crop Yield, Run-off, Soil Loss and Nutrient Loss in Ethiopia: Review and Synthesis

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Abstract Research results published regarding the impact of soil and water conservation practices in the highland areas of Ethiopia have been inconsistent and scattered. In this paper, a detailed review and synthesis is reported that was conducted to identify the impacts of soil and water conservation practices on crop yield, surface run-off, soil loss, nutrient loss, and the economic viability, as well as to discuss the implications for an integrated approach and ecosystem services. The review and synthesis showed that most physical soil and water conservation practices such as soil bunds and stone bunds were very effective in reducing run-off, soil erosion and nutrient depletion. Despite these positive impacts on these services, the impact of physical soil and water conservation practices on crop yield was negative mainly due to the reduction of effective cultivable area by soil/stone bunds. In contrast, most agronomic soil and water conservation practices increase crop yield and reduce run-off and soil losses. This implies that integrating physical soil and water conservation practices with agronomic soil and water conservation practices are essential to increase both provisioning and regulating ecosystem services. Additionally, effective use of unutilized land (the area occupied by bunds) by planting multipurpose grasses and trees on the bunds may offset the yield lost due to a reduction in planting area. If high value grasses and trees can be grown on this land, farmers can harvest fodder for animals or fuel wood, both in scarce supply in Ethiopia. Growing of these grasses and trees can also help the stability of the bunds and reduce maintenance cost. Economic feasibility analysis also showed that, soil and water conservation practices became economically more viable if physical and agronomic soil and water conservation practices are integrated.

Keywords Crop productivity · Ecosystem services · Nutrient depletion · Soil erosion · Soil fertility management

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Introduction

Soil erosion and nutrient depletion has been a major national agenda and remains an important issue in the Ethiopian highlands because of their adverse impacts on crop productivity, environmental sustainability, food security, and the quality of life in general (Kassie et al. 2009; Bewket and Sterk 2002; Hurni 1996). Productivity impacts of soil erosion and nutrient depletion are mainly due to on-site effects: a decline in soil fertility, soil organic carbon and moisture availability and off-site effects such deposition of sediments in irrigation dams (Stroosnijder 2009; Pender and Gebremedhin 2007). Ethiopia has been described as one of the most serious soil erosion areas in the world (Hurni 1993). Although the magnitude varies within the country, several studies confirmed that the significance of soil erosion in the Ethiopian highlands ranged from 42 t ha^{-1} y^{-1} (Hurni 1993) to 175.5 t ha^{-1} y^{-1} (SCRP 2000b). The high variation in soil loss is partly due to variations in slope, rainfall, soil types, land uses, plot size, and method of estimations (Wilcox et al. 2003); and lack of uniformity in the sizes of experimental plots (Stroosnijder 2005). Besides soil losses, it is important to consider run-off and nutrient losses for crop production. Loss of rainwater as run-off limits the water available for crop production (Nyssen et al. 2005; Rao et al. 1998). Despite the importance of soil erosion in affecting the soil nutrient equilibrium, only few available studies have been conducted on this topic in Ethiopia (Haileselassie et al. 2005; Stoorvogel et al. 1993; Stoorvogel and Smaling 1990). Nutrient losses from agricultural land also imply an economic loss to the farmer by both reducing crop yield and increasing the replacement cost of soil nutrients (Yirga and Hassan 2010). Moreover, nutrient losses can contribute to water pollution in downstream areas (Pimentel et al. 1995). With response to these severe soil erosion and nutrient depletion, huge investments in Soil and Water Conservation (SWC) have been implemented by the Ethiopian government since 1980s in the country in collaboration with local community and several donors (Adimassu et al. 2013b; Beshah 2003; Admassie 2000; Shiferaw and Holden 1998; Berhe 1996).

The establishment of a SWC division within the Ministry of Agriculture (MoA) due to the outbreak of the 1973/74 drought was the first initiative of SWC investment in Ethiopian history (Berhe 1996). During that time, SWC investment began in drought prone areas using a food-for-work approach which was mainly funded by the World Bank, World Food Program (WFP) and Food and Agricultural Organization (Berhe 1996). Since the 1980s, various national SWC efforts have been undertaken with the financial support of international donors and mass mobilization of rural communities (Holden et al. 2001). The largest SWC investment made in the country was during the Derg Regime in which more than 1 billion US dollars per year were invested during 1974–1991 (Rahmato 1994). International donors, governmental organizations and local non-government organizations have also invested substantial resources in SWC since the 1990s (Beshah 2003). Since the overthrow of the Derg Regime in 1991, investments in SWC in Ethiopia has continued. For example, more than 500 million US dollar has been invested in the Productive Safety Net Progamme since 2005 in which the majority of the money was allocated to SWC activities (Gilligan et al. 2009; Andersson et al. 2011). Moreover, huge financial resources have been invested in Sustainable Land Management Program (SLMP) since 2008 with the support of World Bank and Global Environmental Facility (Nedassa et al. 2011) and MERET (Managing Environmental Resources to Enable Transitions to sustainable livelihoods) project since 2003 with the financial support of WFP (Zeleke et al. 2014).

There is a long and rich tradition of empirical research that seeks to assess the impact of SWC practices in Ethiopia. Studies demonstrated that physical SWC practices were effective in reducing surface run-off and nutrient loss, and controlling soil erosion (Adimassu et al. 2014; Oicha et al. 2010; SCRP 2000a). However, studies have shown that the impacts of SWC practices on crop yield and the economic viability of SWC practices were inconsistent and results were site-specific. For example, construction of SWC practices such as soil and stone bunds reduced crop yield up to 7 % for the first few years in Ethiopia (Adimassu et al. 2014; Kassie et al. 2011; Kato et al. 2011; Shiferaw and Holden 1999). On the contrary, stone and soil bunds increased crop yield up to 10 % in the Tigray region of Ethiopia (Nyssen et al. 2007; Vancampenhout et al. 2006; Gebremedhin et al. 1999). Also, Teshome et al. (2013), Adgo et al. (2012) and WFP (2005) indicated that SWC practices have positive economic impact whereas Shiferaw and Holden (2001) demonstrated that the economic incentives to invest in SWC practices are very low except for low-cost measures like grass strips. This shows that the results regarding the economic viability of SWC practices are inconsistent and site-specific.

Hence, a more comprehensive review and further synthesis has been undertaken to distill the results of previous research for future use and to guide development and implementation of SWC practices in Ethiopia. The main objective of this study was to assess and synthesize the impacts of SWC within a more systematic basis within the framework of ecosystem services, namely, on provisioning (e.g. crop yield), regulating (e.g., run-off control, soil loss control and nutrient loss reduction) and cultural (e.g., educational and esthetic values) ecosystem services. Moreover, this paper reviews and synthesizes the economic viability of soil and water conservation practices.

Methodology

According to Hudson (1995) and Morgan (2005), SWC practices are grouped in to three major categories: physical, biological and agronomic SWC practices. Whilst there is an overlap in these categories, (for example, by definition, grass strip is categorized as biological SWC practices, but by function, it has the role of physical SWC practices), the three categories are used as a starting point here. Physical SWC practices include stone bunds, soil bunds (level/graded), fanya juu (level/graded). Agronomic SWC practices include compost, farmyard manure (FYM), mulching, minimum tillage (minimum soil disturbance without crop residue), tied-ridging. The only biological SWC practices considered in this study was grass strips. Although, tied-ridging would seem to be a physical SWC practice, it is mostly studied as an agronomic SWC intervention in Ethiopia. Most physical SWC practices are constructed in the sloping areas whereas agronomic and biological measures are mostly applied in relatively flat topography (Kassie et al. 2009; Bewket and Sterk 2002). However, the major limitation of this study was that studies have been conducted in different agro-ecologies and researchers did not systematically describe the characteristics of the study area except rainfall, altitude and slope. Moreover, only average values of rainfall, altitude and slope were presented.

Both electronic and hard copy literature sources were used to collate data on impacts of SWC practices on crop yield, surface run-off, soil loss, and nutrient loss. Several key words were used in searching electronic literature. These include investments, SWC, land management, stone bunds, soil bunds, fanya juu, rehabilitation, FYM, compost, tie-ridge, furrow, Ethiopian highlands, food-for-work, Productive safety net (PSN), effects, impacts, economics of SWC, and Ethiopia. Additionally, publications in hard copy were obtained from libraries of different institutions such as MoA, WFP, Water and Land Resource Center and Ethiopian Institute of Agricultural Research. In this study, a total of more than 100 papers were used for review and synthesis.

Data on the impact of SWC practices such as the impacts on crop yield, run-off, soil loss, nutrient loss, soil fertility improvement, and Net Present Value (NPV) were organized in a database using Microsoft Excel and SPSS. In addition to data on impact indicators, biophysical characteristics (e.g. slope, altitude, rainfall) of the sites of each study were recorded in the database for further analysis. Once the data were organized and structured, different descriptive statistics were conducted to synthesize the data. This was followed by the use of Ordinal Least Square regression to understand how biophysical characteristics of plots (e.g. rainfall, altitude, slope, age of SWC structures) can affect the performance of SWC practices in enhancing ecosystem services. The dependent variable used in the OLS regression was the mean difference of crop yield. The most important explanatory variables included in the OLS regression analysis were age of SWC practices, rainfall, altitude and slope. These explanatory variables were of average values. The small number of explanatory variables is due to the limited description of experimental sites in most of the studies.

Results and Discussion

This section is divided into three sets of results. The first set of results describes the impact of SWC practices on crop yield. The second discusses the impact of SWC practices on surface run-off, soil loss, nutrient loss, and soil fertility improvement. The final results presented relate to the economic viability of different SWC practices, expressed in NPV.

Impacts of SWC Practices on Crop Yield

This section presents the impact of physical and agronomic/biological SWC practices on provisioning ecosystem services and specifically the impacts of SWC practices on crop yield in Ethiopia. Our review and sysnthesis focuses only on grain yield of crops due to the lack of data on biomass yield in most of the publications.

Table 1 presents the details of the impact of SWC practices on grain yield of crops. As shown in the table, the impacts of SWC practices on grain yield of crops were either positive (+), negative (−) or neutral (0). In most of the observations (72 %, $n = 18$), land treated with stone bunds increased gain yield (Table 1). However, only 30 % ($n = 37$) of observations showed that graded fanya juu increased crop yield. Nearly half (49 %, $n = 43$) of graded soil bunds decreased crop yield. A small proportion of the observation of level fanya juu (11 %, $n = 44$) and level soil bund (33 %, $n = 15$) increased crop yield. This suggests that most physical SWC measures are less effective in enhancing grain yield of crops. On the contrary, most agronomic SWC practices increased crop yield (Table 1). For example, more than 86 % ($n = 36$) compost and about 90 % ($n = 78$) FYM applications increased crop yield. Similarly, most of the observations on mulching (88 %, $n = 17$) and tied-ridging (91 %, $n = 103$) increased crop yield. More than half of the observation (56 %, $n = 62$) of minimum tillage experiments and 21 % ($n = 29$) of grass strip experiments increased crop yield.

Table 2 presents a clearer picture of the impact of SWC practices on crop yield. When the mean differences were considered, stone bunds increased crop yield by 322 kg ha^{-1}. Nevertheless, the remaining physical SWC practices such as fanya juu and soil bunds (fanya chini) were related to reduced crop yield, ranging from 54 to 193 kg ha^{-1}. The main reason for the negative yield impact of physical SWC practices is due to yield reduction is likely to have been a result of the reduction in cultivated land taken up by placing the bund in the landscape. Previous results in Ethiopia showed that significant proportion of crop land could be occupied by physical SWC practices (Adimassu et al. 2014; Kato et al. 2011; Shiferaw and Holden 1999). The area occupied by the structures depend on the vertical interval, the base width and the slope of the land. For instance, 30 % of area can be occupied by soil bund if we consider a vertical interval of 2.5 m, base width of 1.5 m and 20 % of land slope. Similar results have been recorded in other countries. For example, in Thailand, the use of contour hedgerows reduced maize grain yield up to 39 % as compared to a control without hedges (Pansak et al. 2008).

Table 1 Details of studies on the impacts of SWC practices on grain yield of crops in Ethiopia: positive impact (+), negative impact (−) and no impact (0)

SWC practices	N	References	Impact
Stone bunds	13	Teshome et al. 2013; Alemayehu et al. 2006; Araya et al. 2012; Araya et al. 2011; Gebremedhin et al. 1999; Nyssen et al. 2007; Vancampenhout et al. 2006	+
Stone bunds	5	Teshome et al. 2013; Oicha et al. 2010	−
Graded Fanya Juu	11	Amare et al. 2013; Teshome et al. 2013; SCRP 2000b; SCRP 2000d; SCRP 2000e; Shiferaw and Holden 1999	+
Graded Fanya Juu	3	SCRP 2000c; SCRP 2000d; SCRP 2000e	0
Graded Fanya Juu	23	Teshome et al. 2013; SCRP 2000a; SCRP 2000b; SCRP 2000c; SCRP 2000d; SCRP 2000e; SCRP 2000f	−
Graded soil bunds	12	Teshome et al. 2013; SCRP 2000a; SCRP 2000d; SCRP 2000e; Shiferaw and Holden 1999; Shiferaw and Holden 1998	+
Graded soil bunds	10	SCRP 2000a; SCRP 2000c; SCRP 2000d; SCRP 2000e; Shiferaw and Holden 1999	0
Graded soil bunds	21	Adimassu et al. 2014; Teshome et al. 2013; SCRP 2000a; SCRP 2000b; SCRP 2000c; SCRP 2000d; SCRP 2000f	−
Level Fanya Juu	5	SCRP 2000a; SCRP 2000d; SCRP 2000e	+
Level Fanya Juu	31	SCRP 2000c; SCRP 2000e	0
Level Fanya Juu	8	Hengsdijk et al. 2005 SCRP 2000a; SCRP 2000c; SCRP 2000d; SCRP 2000f	−
Level soil bund	5	SCRP 2000a; SCRP 2000d; SCRP 2000e	+
Level soil bund	2	SCRP 2000a; SCRP 2000c; SCRP 2000d	0
Level soil bund	8	SCRP 2000a; SCRP 2000c; SCRP 2000d;SCRP 2000f	−
Compost	5	Ayalew 2011	−
Compost	31	Ayalew 2011; Tsigie et al. 2011; Bedada et al. 2014; Edwards et al. 2007; Laekemariam and Gidago 2012	+
FYM	8	Zerihun et al. 2013; Ayalew and Dejene 2012	−
FYM	70	Birru et al. 2012; Balemi 2012; Zerihun et al. 2013; Alemu and Bayu 2005; Bayu et al. 2005; Ayalew and Dejene 2012; Haile et al. 2009; Bekeko 2013	+
Minimum tillage	27	Taa et al. 2004; Tulema et al. 2008; Temesgen et al. 2009; Erkossa et al. 2005; Habtegebrial et al. 2007; Ito et al. 2007; Erkossa et al. 2006; Mesfin et al. 2005; Burayu et al. 2006; Tolessa et al. 2007	−
Minimum tillage	35	Tulema et al. 2008; Erkossa et al. 2005; Ito et al. 2007; Erkossa et al. 2006; Burayu et al. 2006; Aune et al. 2006; Temesgen et al. 2012; Tolessa et al. 2007	+
Mulch	2	Birru et al. 2012	−
Mulch	15	Araya and Stroosnijder 2010; Belay et al. 1998; Mesfin et al. 2005; Birru et al. 2012; Tsigie et al. 2011	+
Tied-ridge	9	Tesfahunegn and Wortmann 2008	−
Tied-ridge	94	Araya et al. 2012; Araya and Stroosnijder 2010; Biazin and Stroosnijder 2012; Brhane et al. 2006; Rockstrom et al. 2009; Gebrekidan 2003; Belay et al. 1998; Bayu et al. 2012; Mesfin et al. 2005; Mesfin et al. 2014; Mesfin et al. 2009; Tesfahunegn and Wortmann 2008; Woldetsadik et al. 2005	+
Grass strip	18	Shiferaw and Holden 1999; SCRP 2000a; SCRP 2000b; SCRP 2000c; SCRP 2000d; SCRP 2000e; SCRP 2000f	−
Grass strip	5	SCRP 2000a; SCRP 2000b; SCRP 2000c; SCRP 2000d; SCRP 2000e	0
Grass strip	6	Shiferaw and Holden 1999; SCRP 2000a; SCRP 2000b; SCRP 2000c; SCRP 2000e	+

In semi-arid Tanzania, maize yield was reduced by 13 % due to the construction of stone bunds (Hatibu et al. 2003). In semi-arid Kenya, Kinama et al. (2007) demonstrated that maize yield was reduced by 55 and 60 % due to use of hedgerows (Senna *siamea)* and grass strips (*Panicum maximum)*, respectively. In the highlands of Kenya, fanya juu bench terraces were also found to be ineffective to improve yield of maize (Kiome and Stocking 1995).

By way of contrast the increase in crop yield due to the use of agronomic SWC practices (except grass strip) ranged (on average) from 108 kg ha^{-1} (minimum tillage) to 3917 kg ha^{-1} (FYM) (Table 2). The main reason for the negative yield impact of grass strips is due to the fact that it occupies cultivable land for hedge formation. Studies in other countries have shown that most agronomic SWC practices increased crop yield considerably. For instance,

Table 2 The impact of soil and water conservation practices on grain yield (mean difference) of crops (kg ha^{-1}) related to rainfall, altitude and slope

SWC practices	*N*	Average annual rainfall (mm)	Average altitude (mm)	Average slope (%)	Yield mean difference (kg ha^{-1})
Stone bund	18	1138.7	2122.8	14.1	321.7
Graded fanya juu	37	1454.3	2344.8	18.7	−53.7
Graded soil bund	43	1417.6	2360.3	16.8	−144.9
Level fanya juu	44	1307.5	2375.8	20.7	−172.7
Level soil bund	15	1030.2	23313	19.82	−193.2
Grass strip	29	1378.3	2390.9	18.6	−158.9
Minimum tillage	62	896.9	1990.3	3.3	108.4
Mulching	17	876.7	2146.6	4.7	629.2
Tied-ridge	103	695.1	2022.8	4.4	554.3
FYM	78	1048.0	1794.6	3.8	3917.9
Compost	36	1228.9	2268.1	2.2	782.9

Table 3 Regression coefficients that affect the impact of physical SWC practices on grain yield of crops

Variables	Estimated coefficients	t-ratio
Intercept	−3495.167	−2.095
Age of SWC practices (yrs)	20.919	1.454*
Average annual rainfall		
Rainfall < 601 mm	1272.261	1.938
Rainfall 601–1000 mm	847.749	3.508
Rainfall > 1000 mm	−650.597	−1.760**
Average slope		
Slope < 15 %	−757.914	−1.331
Slope 15–25 %	−653.768-	−2.157**
Slope > 25 %	−208.855	−0.924*
Average altitude		
Altitude < 1500 m	1300.363	2.061**
Altitude 1500–2000 m	1598.792	1.722**
Altitude > 2000 m	−1562.589	−2.186*
R^2		0.515
Number of observations	142	

*, ** and *** are significant at 10, 5 and 1 % of probabilities, respectively

trashlines (mulch) were found to be effective in improving maize yield in the highlands of Kenya (Kiome and Stocking 1995). Application of compost increased the yield of maize by 13 % (Amoding et al. 2011) and cabbage by 52 % (Karungi et al. 2010) in Uganda. The use of millet stover as mulch material increased yield of millet by 25–80 % in Niger (Lamers and Bruentrup 1996).

Tables 2 and 3 summarize the impacts of SWC practices on crop yield. Accordingly, biophysical characteristics of plots such as age of SWC measures, slope, altitude and rainfall were regressed with crop yield. The relationship between mean difference of crop yield and biophysical characteristics is presented in Table 3. The coefficient of determination (R^2) shows that 51.5 % of the variation in mean difference of crop yield was due to the variables included in the model for physical SWC practices. Similarly, the R^2 for agronomic SWC practices was 47 %. The effects of these variables on crop yield are discussed below. Due to the limitation of the data in most of the publications, only a few variables such as duration of SWC practices, slope, rainfall and altitude were considered in the regression equation and further analysis is required to determine that how other characteristics of plots can affect the performance of SWC practices on crop yield.

Age of SWC Practices (years)

Duration of SWC practices between implementation and evaluation influenced its impact on crop yield. The impact of duration of physical SWC practices on crop yield was positive and significant at 10 % probabilities. This means that the longer the establishment of SWC practices, the better is its impact on crop yield.

Rainfall (mm)

Rainfall also affected the performance of SWC practices on crop yield. To assess the effect of rainfall, we grouped the annual rainfall into three regimes: <600, 601–1000 and >1000 mm. The results suggest that the impact of physical SWC practices is positive, but not significant in rainfall regime less tha1000 mm. However, annual rainfalls greater than 1000 mm influenced the performance of SWC practices negatively and significantly ($p < 0.05$). The negative effect might be due to excessive water availability (water logging) on the furrows of structures. This implies that site-specific recommendation and design requirements of SWC practices are crucial to enhance the effectiveness of physical SWC structures on crop yield.

Slope (%)

Like rainfall, three slope categories were used for regression analysis. These include: slopes <15 %, slopes between 15 and 25 %, and slopes >25 %. As shown in Table 3, the coefficients of all slope categories were negative and significant. However, the negative coefficients decrease with increasing slope indicating that yield on steep slopes are higher than on gentle slopes. This might be due to the fact that water logging (excessive water) effect of level bunds in high rainfall areas.

Altitude (m)

SWC practices in Ethiopia have been implemented over a diverse range of altitudes. The performance of physical SWC practices on crop yield increases with altitude. However, the effect of altitude on crop yield was negative in studies conducted at >2000 m above mean sea level. This might be due to the fact that higher altitude might be associated with higher rainfall which leads to waterlogging during the growing period of crops. Moreover, the impact of decreasing temperature with altitude giving rise to less biomass and grain yield regardless of SWC practices.

Impact of SWC Practices on Surface Run-Off, Soil Loss and Nutrient Loss

Impact on Surface Run-Off Control

Results from the analysis indicated that physical and agronomic SWC practices were effective in reducing surface run-off (Table 4). The reductions in surface run-off ranged from 9 % (FYM) to 76 % (mulch). This indicates that surface run-off is greater in less fertile bare soils. The high effect of mulch in controlling surface run-off is due to the fact that it improves the infiltration rate of the soil and reduce the detachment of soil particles by dissipating the erosive impacts of rain drops. In the only available Ethiopian study found on minimum tillage (Erkossa et al. 2005), run-off under minimum tillage was higher than for the control treatment. High run-off under minimum tillage could be attributed to hard soil surface limiting the infiltration of water at the beginning of rainfall. Similar results were observed elsewhere in which run-off from minimum tillage were higher compared with the control treatment (Okeyo et al. 2014; Liu et al. 2011). This suggests the need to apply enough mulching material (crop residue) for minimum tillage to enhance infiltration and reduce soil detachment by raindrop impact. Studies in other counties showed that most SWC practices controlled surface run-off. For example, hedgerows of *Cassia siamea* reduced losses of run-off up to 23 % and hedgerows with mulch up to 41 % (Kiepe 1996) in semi-dryland Kenya. Moreover, application of FYM reduced run-off up to 62 % in the United States of America (Gilley and Kisse 2000). A study in India showed that tied ridging reduced surface run-off by 69 % as compared with control treatments (Kurothe et al. 2014).

Impact on Soil Erosion Control

The results from the studies analyzed demonstrated that both physical and agronomic SWC practices reduced soil loss (Table 5). The reductions in soil erosion (expressed as soil loss, t ha^{-1}) ranged from 12 % in FYM treatments to 98 % in mulching treatments. Of the physical SWC practices, level soil bunds were effective in reducing soil loss up

Table 4 The impact of SWC practices on surface run-off in Ethiopia

SWC practices	*N*	With (mm)	Without (mm)	Change (mm)	Change (%)	References
Graded soil bund	66	142.7	190.7	−48.0	25.2	Adimassu et al. 2014; SCRP 2000a; SCRP 2000b;SCRP 2000c;SCRP 2000d; SCRP 2000e; Herweg and Ludi 1999
Level soil bund	52	51.3	128.5	−77.3	60.1	SCRP 2000a; SCRP 2000b;SCRP 2000c; SCRP 2000d; SCRP 2000e; Herweg and Ludi 1999
Stone bund	4	157.8	240.5	−82.7	34.4	Araya et al. 2011; Gebreegziabher et al. 2008; Oicha et al. 2010;
Tied-ridge	4	37.5	84.8	−47.3	55.8	Araya et al. 2011; Araya et al. 2012; Araya and Stroosnijder 2010
Grass strip	34	81.2	140.0	−58.8	42	SCRP 2000a; SCRP 2000b; SCRP 2000c SCRP 2000d; Herweg and Ludi 1999; Kebede and Yaekob 2009; Welle et al. 2006
FYM	3	36.2	39.7	−3.3	8.8	Birru et al. 2012
Minimum tillage	5	170.9	143.1	27.8	19.4	Erkossa et al. 2005; Woyessa and Bennie 2007
Mulch	9	8.7	35.5	−26.8	75.5	Araya and Stroosnijder 2010; Birru et al. 2012; Woyessa and Bennie 2007

Table 5 The impact of soil and water conservation practices on soil erosion control in Ethiopia

SWC practices	*N*	With (t ha^{-1})	Without (t ha^{-1})	Change (t ha^{-1})	Change (%)	References
Graded soil bund	67	17.9	43.6	−25.7	59	Adimassu et al. 2014; SCRP 2000a; SCRP 2000b; SCRP 2000c;SCRP 2000d; SCRP 2000e; Herweg and Ludi 1999; Shiferaw and Holden 1999
Level soil bund	48	2.1	17.5	−15.4	88	SCRP 2000a; SCRP 2000b; SCRP 2000c; SCRP 2000d; SCRP 2000e; Herweg and Ludi 1999
Stone bund	4	12.4	20.0	−7.6	38	Araya et al. 2012; Araya et al. 2011; Gebreegziabher et al. 2008; Oicha et al. 2010
Grass strip	30	5.9	28.3	−22.4	79	SCRP 2000a; SCRP 2000b;SCRP 2000c; SCRP 2000d; Herweg and Ludi 1999; Shiferaw and Holden 1999; Welle et al. 2006
FYM	3	8.6	9.8	−1.2	12	Birru et al. 2012
Minimum tillage	3	2.5	2.2	0.3	14	Erkossa et al. 2005
Mulch	3	0.2	9.8	−9.6	98	Birru et al. 2012
Tied-ridge	2	9.5	25.0	−15.5	62	Araya et al. 2012; Araya et al. 2011

to 88 % (15.9 t ha^{-1}). This is because; level bunds retain soil and water across the slope. Although the percentage of soil loss from using graded soil bunds is smaller (59 %), the amount of soil loss reduced by this bund is larger (25.7 t ha^{-1}) than all SWC practices. This might be due to the fact that graded soil bunds are constructed in higher rainfall area where soil erosion is very severe. The use of appropriate mulching material reduced soil erosion up to 98 %. The main reason for the effectiveness of mulch in reducing soil loss is that it prevents soil detachment by rain drops and thereby the amount of soil transported by the run-off. However, a study on minimum tillage (Erkossa et al. 2005) showed that soil losses under minimum tillage was higher than for the control treatment. Similar results were observed in the highlands of Kenya at Meru in which soil loss under minimum tillage were higher as compared with the control treatment (Okeyo et al. 2014). However, the same study indicated that mulching had reduced soil loss by 41 and 71 % during both the long and short rainy seasons, respectively (Okeyo et al. 2014).

Impact on the Reduction of Soil Nutrient and Organic Matter Losses

Table 6 shows that SWC practices were effective in reducing the loss of soil organic matter (OM), and soluble and sediment associated soil nutrients. For example, graded soil bund reduced the loss of soil OM up to 52 %, total nitrogen up to 48 %, and available phosphorus up 41 % (Table 6). The loss of soluble soil nutrients via surface run-off, particularly the loss of phosphorus impair surface water quality downstream through nutrient enrichment and potential eutrophication which affects the provision of clean water for domestic and irrigation purpose. Similar results have been observed elsewhere that use of SWC practices reduced losses of soluble and sediment associated soil nutrients (Adimassu et al. 2014). On the contrary, the use of minimum tillage aggravated the losses of total nitrogen (177 %) and available phosphorus (63 %) (Table 6). The higher nutrient loss due to implementation of minimum tillage is likely a result of higher surface run-off (Table 4) and soil loss (Table 5) in the minimum tillage treatments. A study in the dryland parts of India showed that solution phosphorus concentrations and losses were higher from minimum tillage as compared with conventional tillage treatments (Sharma et al. 1988).

Impact on Soil Fertility Improvement

The results in Table 7 present the fertility condition of the soil with and without SWC practices. Results indicate that soils treated with SWC practices had higher nutrient content when compared with soils that are not treated with SWC practices. Improvements in OM ranged from 0.3 % (in soil bund) to 0.7 % (in compost). The enhancement of total nitrogen content ranged from 0.02 % (in soil bund) to 0.05 % (in FYM), while available phosphorus was improved from 0.3 ppm (in soil bund) to 8.5 ppm (in FYM). The positive mean differences in soil fertility can be explained in two ways. Firstly, most SWC practices reduce losses of soluble and sediment bound soil nutrients (Table 4). Secondly, most agronomic SWC practices such as application of compost, FYM and mulch directly increase the nutrient content of the soil through decomposition processes. Our results demonstrated that SWC practices significantly reduced run-off, soil loss and nutrient loss as opposed to crop yield. This shows that there is a trade-off between crop yield, and reduced run-off, soil loss and nutrient loss. This requires a mechanism to motivate farmers

Table 6 The impact of SWC practices on nutrient loss in Ethiopia

SWC practices	*N*	With (kg ha^{-1})	Without (kg ha^{-1})	Change (kg ha^{-1})	Change (%)	References
OM loss (kg ha^{-1})						
Graded soil bund	4	7.8	16.1	−27.5	52	Adimassu et al. 2014
Minimum tillage	4	24.9	25.2	−0.3	1	Erkossa et al. 2005; Habtegebrial et al. 2007
Total Nitrogen loss (kg ha^{-1})						
Graded soil bund	4	30.4	57.9	−27.5	48	Adimassu et al. 2014
Minimum tillage	12	9.7	3.5	6.2	177	Erkossa et al. 2005; Habtegebrial et al. 2007
Available Phosphorus (kg ha^{-1})						
Graded soil bund	4	86.5	145.5	−59.0	41	Adimassu et al. 2014
Minimum tillage	12	6.5	4.0	2.5	63	Erkossa et al. 2005; Habtegebrial et al. 2007

Table 7 The impact of SWC practices on soil fertility improvement in Ethiopia

SWC practices	*N*	With	Without	Change	Change (%)	References
OM (%)						
Stone bunds	11	2.6	2.1	0.5	24	Assefa 2007; Damene et al. 2012; Demelas and Stahr 2010; Gebre-Selassie and Belay 2013; Wolka et al. 2011; Vagen et al. 1999
Soil bunds	4	2.6	2.2	0.3	14	Amare et al. 2013; Wolka et al. 2011
Mulch	5	3.3	2.9	0.5	17	Tsigie et al. 2011; Zeleke et al. 2004
FYM	20	3.2	2.6	0.6	23	Abera et al. 2005; Ayalew and Dejene 2012; Bayu et al. 2006; Tadesse et al. 2013
Compost	3	4.9	4.2	0.7	17	Tsigie et al. 2011
Total N (%)						
Stone bunds	11	0.20	0.16	0.04	25	Assefa 2007; Damene et al. 2012; Gebre-Selassie and Belay 2013; Wolka et al. 2011; Vagen et al. 1999
Soil bunds	4	0.15	0.13	0.02	15	Amare et al. 2013; Wolka et al. 2011
Mulch	3	0.27	0.22	0.05	23	Tsigie et al. 2011
FYM	17	0.29	0.24	0.05	21	Abera et al. 2005; Ayalew and Dejene 2012; Bayu et al. 2006; Tadesse et al. 2013
Compost	3	0.26	0.22	0.04	18	Tsigie et al. 2011
Available P (ppm)						
Stone bunds	11	10.2	9.9	0.3	3	Assefa 2007; Damene et al. 2012; Gebre-Selassie and Belay 2013; Wolka et al. 2011; Vagen et al. 1999
Soil bunds	4	9.0	8.3	0.7	8	Amare et al. 2013; Wolka et al. 2011
Mulch	3	25.4	18.6	6.8	37	Tsigie et al. 2011
FYM	17	17.8	9.3	8.5	91	Abera et al. 2005; Ayalew and Dejene 2012; Bayu et al. 2006; Tadesse et al. 2013
Compost	3	25.6	18.6	7	38	Tsigie et al. 2011

to invest in management interventions that improve regulating and supporting ecosystem services.

Financial Viability of SWC Practices

Although the empirical literature on cost-benefit analysis of SWC practices in Ethiopia is very limited, there have been some studies that have estimated the NPV of different SWC practices. As shown in Table 8, cost-benefit analysis was conducted for only physical SWC practices which were constructed at different altitude ranges, 1525 m a. s. l. (e.g. level soil bund) to 3136 m a. s. l. (level fanya juu). These areas receive annual rainfalls varying from 500 to 1790 mm. The synthesis and analysis showed that NPV were calculated with time horizons of investments in SWC varied between 15 and 25 years and discount rates ranging from 12 to 17 %. Although, on average, the impacts of physical SWC practices on crop yield were negative (Table 2), the NPV of most physical SWC practices were positive (except graded fanya juu and graded soil bunds), and the NPV

Table 8 Summary of economic viability expressed in NPV for selected SWC practices in Ethiopia. 1 USD = 21.5 ETH Birr in July 2016

SWC practices	Sample size	Rainfall (mm)	Altitude (m)	Time horizon (yrs.)	Discount rate (%)	NPV (Birr/ha)	References
Bench terrace	4	769.00	1992.50	25.00	12.00	2794.0	WFP 2005
Stone bund	9	905.67	2251.67	23.89	12.11	3486.2	Teshome et al. 2013; WFP 2005
Level fanya juu	14	1370.43	3135.86	16.07	11.75	5283.4	Teshome et al. 2013; WFP 2005
Graded fanya juu	27	1598.00	2826.00	15.00	17.14	−148.2	Shiferaw and Holden 2001; Teshome et al. 2013
Graded soil bund	27	1598.00	2826.00	15.00	17.14	−708.0	Shiferaw and Holden 2001
Graded fanya juu + grass	2	1790.00	2450.00	20.00	12.50	2130.0	Adgo et al. 2012; Teshome et al. 2013
Level soil bund	24	1191.96	2696.54	19.58	11.90	1675.8	Teshome et al. 2013; WFP 2005
Level soil bund + trench	1	500.00	2350.00	25.00	12.00	2244.0	WFP 2005
Level soil bund + grass	2	1525.00	2375.00	20.00	12.50	1860.5	Teshome et al. 2013; WFP 2005
Grass strip	27	1598.00	2826.00	15.00	17.14	4073.9	Shiferaw and Holden 2001

varied between 1675 and 5283 ETH Birr ha^{-1} yr^{-1}. This implies that investments in SWC measures are financially viable against crop yield. However, this result contradicts the results in Table 2 where the average crop yield impact for most physical SWC practices is negative. This mismatch between the impact of SWC on crop yield and NPV, attributed to cost-benefit analysis of SWC practices is more comprehensive than simply assessing the impact of SWC on crop yield. Cost-benefit analysis assumed several on-site and off-site costs and benefits of SWC practices. Most important costs included in the studies were initial construction costs, ongoing maintenance costs of SWC structures, and production costs of crops. The major benefits considered were increased soil depth, reduced soil loss, reduced nutrient loss, reduced sedimentation of reservoirs, soil moisture retention, and crop productivity. Moreover, cost-benefit analysis considers long time-horizon to calculate the NPV.

The negative NPV for graded fanya juu (NPV = −148 ETB ha^{-1}) and graded soil bunds (NPV = −708 ETB ha^{-1}) might be due to lack of exhaustive inclusion of on-site and off-site benefits of SWC practices during cost-benefit analysis. However, these structures became economically profitable when grasses were planted on bunds and the price for these grasses was considered in cost-benefit analysis. The NPV of graded fanya juu increased from −148 to 2130 ETB ha^{-1} when grass was planted on the bund. When level soil bunds were integrated with trench, the NPV increased from 1676 to 2244 ETB ha^{-1}. When we compare the results of Tables 2 and 8, the impact of grass strip on crop yield was negative (Table 2) while its economic impact was positive (Table 8). This is because the value of the strip (grass) was considered as a benefit during the cost-benefit analysis. Table 8 also shows that when level soil bunds was integrated with grass or trench, the NPV increased significantly. These results indicate that effective use of the area occupied by physical SWC practices (such as bunds) through multipurpose grasses and forage trees on the bunds may offset the yield lost due to a reduction in planting area. In general, different underlying assumptions during the analysis can change the cost-benefit result considerably and consequently also change the conclusion regarding circumstances under which SWC practices can be or not be profitable. The results in Table 8 clearly show that integration of biological and agronomic SWC measures with physical SWC structures is crucial to increase farmers' economic incentives from their investments. A study in the highlands of Rwanda showed that bench terrace alone would be hardly profitable and it only became profitable when animal manure was applied to increase crop yield (Bizoza and De Graaff 2012). A study in mountainous, Peru (Posthumus and De graaff 2005) showed that physical SWC structures (e.g. bench terrace) cannot be profitable unless integrated with agronomic SWC techniques such as planting method, fertilization and crop rotation.

Implications of the Impacts of SWC Practices

This paper has presented the impact of SWC practices on crop yield, run-off, soil loss, nutrient loss, and soil fertility improvement based on a synthesis and analysis of previously published work. Collectively, the impacts of SWC practices have wide ranging implications. This section provides a discussion of two major implications of the impacts of SWC practices: implications for an integrated approach and ecosystem services.

Implications for Integrated Approach

Integration of multiple interventions through combining agronomic SWC practices (e.g., mulch and FYM) with physical SWC measures improve soil nutrient as compared with single physical SWC measures (Table 7). Also, physical SWC measures become financially viable when integrated with agronomic SWC practices (Table 8). Such results suggest that integrating physical and agronomic SWC practices is crucial to enhance the benefits from conservation practices. In principle, several agronomic SWC practices are recommended as major components of participatory watershed management in Ethiopia (Adimassu et al. 2015; Desta et al. 2005). However, the integration of agronomic SWC practices with physical SWC measures is rarely implemented. This is mainly due to the fact that, unlike the physical SWC practices, strategy on how to implement agronomic practices and integrate them with physical SWC practices is not available. The implementation of agronomic SWC practices is up to the individual land owner while the implantation of physical SWC practices is based on different Ethiopian government strategies such as food-for-work, mass mobilization and using different projects such as MERET, PSNP and SLMP. A review of the ongoing SLMP (Sustainable Land Management Plan), there is no mechanism of how to implement agronomic SWC practices. Moreover, agronomic SWC practices have not been given due attention at different levels in the country. This suggests the need for clear implementation and monitoring strategies of integrating agronomic practices with physical SWC practices. Further, the area occupied by SWC structure such as soil bunds can be used as niche for integrating biological SWC practices such as planting of grasses and high value trees on the banks of bunds. Such integration of physical and biological SWC practices could enhance animal feed and compensate the loss of crop yield due to occupation of structures. This would also have the potential added benefit of allowing farmers to consider carry and collect livestock practices rather than traditional free-range grazing which is related to increased soil erosion and land degradation.

Implication for Ecosystem Services

Ecosystem services include the multiple benefits that human being receives from environment (Millennium Ecosystem Assessment (MEA) 2005). Maintaining or enhancing ecosystem services that can be obtained from an ecosystem is one of the benefits of SWC practices. Degradation of water, soil and vegetation, as well as greenhouse gas emissions contributing to climate change, can be limited by SWC practices that simultaneously conserve natural resources and increase crop yields. The ecosystem services provided through SWC practices include provisioning, regulating, supporting, and cultural/ social services (Flesken and Hubacek 2013; Boyd and Banzhaf 2007; Swintona et al. 2007).

The SWC practices implemented in the Highlands of Ethiopia are key in maintaining and/or increasing provisioning ecosystem service through increasing crop productivity and contributing to improved water quality (Roesch-McNally and Rabotyagov 2016; Flesken and Hubacek 2013). SWC practices could also contribute to maintain or enhance regulating ecosystem services by increasing water infiltration in the soil, which results in lower surface run-off and associated high levels of soil erosion. The increase in water infiltration and the reductions in surface run-off preserve soil moisture (for plant production), regulates rivers, lakes, reservoirs and groundwater levels, regulate water discharge from highland to lowland areas, reducing floods and increasing low flows. SWC practices also have a role in the rebuilding of carbon pools in soil and vegetation cover and in decreasing the release of CO_2 to the atmosphere, as well as adapting climate change. SWC practices also have a role in providing and supporting ecosystem services. For example, SWC practices: (i) mitigate soil degradation and enhance soil development, (ii) increase soil moisture enabling soil development and functioning, (iii) enhance primary production and nutrient cycling, and can, (iv) preserve biodiversity at the farm and landscape levels through potential 'land sparing (Wainger and Mazzotta 2011) and agroforestry.

In addition to maintain or enhance provisioning, regulating and supporting ecosystem services, SWC practices help keep alive cultural landscapes and protect cultural heritage. SWC practices also support to valorize indigenous knowledge and production methods and enhance ecotourism (Wainger and Mazzotta 2011). Konso cultural landscape is the spectacular example of a living cultural ecosystem services of SWC practices in Ethiopia. The cultural landscape covers 23,000 ha and registered by UNESCO as outstanding universal value in the World heritage list (UNESCO 2011). For the last several decades, Konso cultural landscape is the most important tourist, research and education area in Ethiopia. This implies that restoration of degraded landscapes and agricultural lands through the implementation of integrated SWC practices is crucial to improve cultural/societal services of the country.

Among these ecosystem services, the impacts of SWC practices reviewed in this paper provide considerable regulating and supporting ecosystem services. The impact of SWC practices in reducing run-off implies the increase in infiltration and ground-water recharge. This improves ground water availability (provisioning service) and regulates water balance through reducing droughts and floods (regulating service). Similarly, the impact of SWC practices on the reduction of soil erosion provides regulating services through reduction of sedimentation of reservoirs and lakes. On the one hand, reduction of nutrient loss and improvement of soil nutrient (using mulching) provide supporting services. On the other hand, reduction of OM loss from the soil (Table 6) and accumulation of OM in the soil (Table 7) indicate carbon sequestration in the soil and hence SWC can be used as one element of a wider strategy to adapt to climate change. These regulating and supporting ecosystem services from SWC practices benefit not only land owners (farmers) but also other communities beyond the investment areas and the future generation. This means farmers are investing to enhance ecosystem services. Hence, we argue that farmers should be paid for the ecosystem services that they provide. This can be done using payment for ecosystem services approach. According to Flesken and Hubacek (2013) and Palm et al. (2014), investments in SWC practices should be supported with PES for the sustainable development. Hence, ecosystem-based SWC approach can be embedded into national SLM strategy by adopting PES.

The impact of SWC on crop yield is the major provisioning ecosystem services of SWC practices. However, provisioning services (crop yield) is negative for the first few years due to significant area loss occupied by physical SWC structures. On the one hand, based on the design of the structure and the slope of the land, physical SWC occupy up 30 % of the cultivated land. The improvement of crop yield due to SWC practices is not sufficient to compensate this loss. On the other hand, poor farmers will have little interest in adopting SWC practices that only offer long term environmental services, particularly if there are short term costs. Hence immediate tangible financial benefits to the community or individual farmers are prerequisite for the adoption of SWC practices. Designing strategies to improve farmers' income in the short-term and to provide incentives at household and/or community levels is crucial to adopt SWC practices at a wider scale. For example, provision of clean domestic water for the community can be used as an incentive for farmers' investments in SWC at watershed scale. Such incentives can motivate farmers to invest more in SWC practices (Sumarga and Hein 2014; Kessler 2007). This also suggests that further thought needs to be built into the intervention schemes to stop or reduce the destruction of SWC measures in their first few years before they become profitable in the medium term.

Conclusions and Recommendation

Our review and synthesis has shown that most physical SWC practices are not successful in improving crop yield. This is because these structures reduce the effective cultivable area and introduce a yield reduction at least in the short-term. The combined effect of the reduction in effective area planted and the high initial investment cost (mostly labor) imply that returns to physical SWC practices may be negative, especially in the first few years. However, it suggested that most SWC practices were successful in improving soil fertility, controlling soil erosion, and reducing surface run-off and nutrient loss. Such results suggest that farmers' investments on SWC provided positive inputs to regulating and supporting ecosystem services. This implies, there is a trade-off between the impact of SWC practices on provisioning and regulating ecosystem services. Furthermore, the results demonstrate that integrating physical SWC practices with agronomic/biological SWC practices is key to enhance the ecosystem services and the economic viability of conservation measures.

Usually, societal benefits related to regulating ecosystem services such as reducing flooding, water pollution and sedimentation, biodiversity conservation, carbon sequestration are overlooked by resource limited farmers. Moreover, farmers are not recognized or are not rewarded for such ecosystem services that they provide. This implies that there is a need to reward or compensate farmers for their investments in SWC practices. Co-investment is a form of rewarding mechanism for ecosystem services in which multiple capitals such as natural, physical, financial, human, social and institutional can be pooled; risks and benefits can be shared among investors for sustainable development is needed (Lopes and Videira 2016; Adimassu et al. 2013a; Van Noordwijk and Leimona 2010). Therefore, there is a need to explore different potentials of co-investments in SWC practices where several beneficiaries and other stakeholders in Ethiopia benefit from the range of ecosystem services delivered by effective SWC programs. Co-investments in farmers' basic needs such as drinking water, high yielding variety, infrastructures (e.g. roads, schools, and health center) can motivate farmers to invest in long-term SWC interventions. Moreover, the impact of SWC practices in Ethiopia has been undertaken from perspective at individual households or plot. This suggests the need to conduct further studies to determine the impacts of SWC practices (including costs and benefits) beyond individual households' perspective in Ethiopia.

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Compliance with ethical standards

Conflict of Interest The authors declare that they have no competing interests.

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