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Review Paper

Effects of land management practices and land cover types on soil loss and crop productivity in Ethiopia: A review

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A B S T R A C T

Identifying land management practices (LMPs) that enhance on-site sediment management and crop productivity is crucial for the prevention, reduction, and restoration of land degradation and contributing to achieving land degradation neutrality (LDN). We reviewed studies in Ethiopia to assess the effects of LMPs on soil loss (84 studies) and crop productivity (34 studies) relative to control practice. Yield variability on conserved lands was assessed using 12,796 fixed plot data. Effects of LMP on soil loss were 0.5–55 t $ha^{-1}y^{-1}$ compared to control practices yielding 50 to 140 t $ha^{-1}y^{-1}$. More than 55% of soil loss records revealed soil loss less than the tolerable rate (10 t ha^{-1}). Area closure, perennial vegetation cover, agronomic practices, mechanical erosion control practices, annual cropland cover, and drainage groups of practices led to 74.0 ± 18.3%, 69.0 ± 24.6%, 66.2 ± 30.5%, 66.1 ± 18.0%, 63.5 ± 20.0%, and 40 ± 11,1% soil loss reduction, respectively. A yield increase of 25.2 ± 15.0%, 37.5 ± 28.0%, and 75.4 ± 85.0% was found from drainage, agronomy, and mechanical erosion control practices, respectively. The average yield loss by erosion on fields without appropriate land management practice and on conserved fields was 26.5 ± 26.0% and 25 ± 3.7%, respectively. The findings suggest that practices that entail a continuous presence of soil cover during the rainy season, perennial vegetation, retention of moisture, and barriers for sediment transport were most effective at decreasing soil loss and increasing productivity. This review provides evidence to identify the best LMP practices for wider adoption and inform decision-making on LMP investments towards achieving sustainable solutions to reverse land degradation.

Contents

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1. Introduction

The interest in the nexus between land degradation, ecosystem services, and food insecurity has increased over years. The negative impacts of land degradation, specifically accelerated soil erosion processes caused by deforestation, overgrazing, conventional tillage, and unsustainable agricultural practices are well known (Borrelli et al., 2021; Nearing, 2013). The impacts are severe not only through land degradation but through fertility loss and off-site impacts (Boardman & Poesen, 2006). This increasing pressure on land calls for multi-use of land and the restoration of degraded lands (Keesstra et al., 2018; Visser et al., 2019). It is thus realized that rehabilitated environments play a central role in the provision of ecosystem services and achieving the UN's Sustainable Development Goals (Yirdaw et al., 2017). One of the SDGs is achieving a Land Degradation Neutrality (LDN) world (target 15.3). The concept of LDN aims to respond to the need for urgent action to reverse land degradation (Borrelli et al., 2017; López-Vicente et al., 2020). Achieving LDN would decrease the environmental footprint of agriculture and supporting food security (Yoshimura et al., 2015). To reverse the pressure on land degradation, actions should be taken that bring sustainable land management (SLM) solutions encompassing soil, water, and vegetation management practices. These practices are essential to enhance ecosystem functions and services, improve food security as well as stabilize the current state of land degradation, and contribute to achieving LDN (Abera et al., 2020; Liniger et al., 2019; Yirdaw et al., 2017). However, in a country like Ethiopia with a very low land-to-man ratio, large livestock population, and unsustainable crop management causing land degradation, achieving an LDN is challenging. The annual cost of land degradation is about $4.3 Billion; where the use of land degrading practices in maize and wheat farms alone account for a loss of $162 million (Gebreselassie et al., 2015). Despite these negative economic impacts, evidence on best bet land management practices for making an informed decision and its contribution to sustainable development targets is not systematically documented. Knowledge and information about the benefits of land management practices to support achieving LDN targets and ecosystem benefits gained from protected and conserved landscapes through land management practices are essential to facilitate targeting and scaling. To gauge the level of achievement of LDN targets and mitigate the risks of land degradation, there is a need to identify best-bet practices with enhanced ecosystem benefits. There is thus a need to systematically synthesis empirical data and identify the best bet in terms of increasing productivity and reducing soil loss across ranges of environmental and farming systems. Therefore, a review of land management and land cover practices and quantify their effects on soil erosion and productivity is the research area we need to act to reduce non-sustainable land resource management and create enabling conditions to transition toward sustainable land management.

In Ethiopia, for the last four decades, community-based land restoration efforts have enabled the implementation of various SLM measures. A recent study in the Ethiopian highlands reported 7.7 million ha (23% of the area requiring restoration) of land has already been covered with land management interventions (Bantider et al., 2019). On the other hand, there are growing impact studies of land management practices on soil loss and crop productivity (Amare et al., 2014; Araya & Stroosnijder, 2010; Ebabu et al., 2019; Erkossa et al., 2006; Herweg & Ludi, 1999; Mekuria et al., 2007; Melaku et al., 2018; Subhatu et al., 2017; Taye et al., 2015; Temesgen et al., 2012). It is thus necessary to note that there is widespread site-specific research conducted to assess the effects of LMP and land cover types on soil loss, runoff, and crop yield. However, regardless of the large extent of interventions, the number of studies conducted to assess the impact of landscape restoration interventions and synthesis of a range of LMP is small. Few review studies in soil and water conservation practices have been conducted in Ethiopia (Abera et al., 2020; Adimassu et al., 2017) and East Africa (Wolka et al., 2018). A recent review study collated peer-reviewed publications until August 2018 and characterized the impacts of national land restoration initiatives on ecosystem services (Abera et al., 2020). Their review work combined measured and model-based case studies and provided a broader picture of the impact of land restoration in Ethiopia. However, despite a growing number of field-based experiments over the years, the effectiveness of the different specific practices has not been systemically analyzed and reported, which undermines informed decision-making related to land restoration investments. It is thus essential to assess the comparative magnitude of soil loss reduction and yield increment induced by different categories of LMP and land cover types at plot level.

This study aimed to provide evidence on best bet SLM practices that enhance ecosystem services and estimate yield loss due to on-site soil erosion. The objective of this study is to review and synthesize published plot-level experiments investigating impacts of different forms of LMPs and land cover types, and specifically to (a) assess impacts of LMP practices on soil loss rates and crop yield relative to the control practice; (b) evaluate the associated on-site yield loss by soil erosion; (c) analyze the differences in ecosystem benefits gained by SLM practices in terms of soil loss reduction and yield increment. The results of the analysis will (i) provide alternative LMPs for targeting SLM and serving as a benchmark for planning; (ii) enable experts and planners engaged in land restoration to compare and identify best land management practices on their relative effectiveness on soil loss reduction and yield gain and would have a significant contribution to the scaling up efforts of SLM in the country; (iii) lead to guide decisions on land restoration investment at the national scale and contribute to achieving LDN targets.

2. Materials and methods

2.1. Literature search

We conducted a literature search and document sourcing using an online search of “keywords” in major websites that provide access to scientific research, e.g., ResearchGate, Google Scholar, and

Table 1
Description of groups of LMP and land cover types and counter control practices.

Treatment practice	Description	Control practice
Drainage practices: broad bed and furrow (BBF), ridge and furrow (RF), camber bed, permanent raised bed, and traditional farm ditches constructed at 2–3m interval.	Practices to drain excess runoff and excess soil moisture	Flatbed
Mechanical erosion control practices: Bench terrace, level soil bund, level fanya juu, graded soil bund, graded fanya juu, stone bund, stone bund + trench, graded fanya juu + trench, check dam, grass strip, bunds combined with hedgerows, tie-ridge, and so on.	Cross slope physical barriers to retard runoff velocity and break slope length	Without SWC; Bare land or fallow
Agronomic practices: Zero tillage, minimum tillage, conservation tillage, mulching, farmyard manure, non-trampling; intercropping, buffer strip cropping, contour strip cropping.	Combination of cropping system, tillage, and moisture conservation techniques	Monocropping; Conventional tillage; bare cover
Annual cropland cover (sole crop): Vetch cover, taro, maize, teff, any annual crop cover,	Annual crop covers and crop management practices	fallow; bare cover
Area closure: Area closure management	Degraded areas being protected and closed from any interference and reduce the intensity of use	Degraded or Bare cover
Perennial vegetation cover: Eucalyptus plantation, grassland, grazing land, shrubland, rangeland	Perennial vegetation on non-arable lands	Degraded bare land

ScienceDirect. In the online search, we used keywords such as 'soil loss', 'soil erosion', 'sediment yield', 'sediment deposition', 'SLM practices', 'soil conservation practices', 'conservation agriculture', 'land cover management techniques', 'crop yield', and 'Ethiopia'. After the initial search result, further screening was made based on certain criteria: 1) considering plot-level experiments that reported soil loss rates due to LMP practice; 2) plot-level studies that report changes in soil loss and crop yield due to LMP practices relative to control practices; 3) excluding model-based estimations and watershed level experiments; 4) when a single experiment reported soil loss rates and/or change in soil loss separately for land conservation practices and land cover management, the two categories of practices were recorded separately. Articles published between 1983 and 2019 were included. This period was selected because several improved soil and water conservation and land management practices were introduced in the early 1980s through the then Soil Conservation Research Programme (SCRP) in seven watersheds across the country. Many impact studies on land management practices then began from this period onwards.

2.2. Analysis of soil loss and crop yield data

Soil loss rates and crop yield in response to LMP practices relative to control practice were the variables subjected to analysis. The analysis was done on soil loss rates and crop yield based on a review of studies that consider the effects of LMP practices under different environmental settings. It is recognized that some LMP has specific environmental requirements and others have wider adaptation conditions. In this review analysis, we assumed that the synthesis of soil loss and crop yield from studies conducted across a wide range of conditions can provide average values and represent the mean effect of an LMP. Based on this assumption, first, the review studies were used to synthesize the effects of LMP on the magnitude of soil loss rates across studies. This analysis helps to assess the relative efficiency of practices and identify those practices that reduce soil loss below the tolerable limit (average value of 10 t ha^{-1} and a range of 2–18 t ha^{-1}) which was determined by Hurni (1985) for Ethiopian conditions. Second, the effects of land management practices were assessed in terms of the rate of changes in soil loss and crop yield relative to control practices. For simplicity, we also compared different groups of LMP and land cover types (Table 1) in terms of their benefits in reducing soil loss rates and increasing crop yield.

2.3. Estimation of yield loss due to soil erosion

The LMP is considered an investment for which significant benefits are expected later and for years to come. On the contrary, costs are incurred when there is inaction to implement and adopt appropriate land management practices. The yield losses due to soil erosion were assessed and quantified under with and without LMP practices. First, yield loss due to the inaction of land management practice was assessed using the review studies dataset on crop yield. The yield loss was estimated on control or conventional practice relative to the yield obtained by applying alternative land management practices. Finally, we pooled yield loss due to the inaction of different LMP practices and calculated the mean percent yield loss for different crop types.

Second, we estimated yield variability or gap induced by erosion gradient between erosion and deposition zones on conserved fields. Because of conservation or erosion control principles, conservation measures aim towards bench formation and control on-site transport of sediments. It is thus assumed that yield variability induced by on-site erosion or transport of sediment over bund areas is considered as on-site yield gaps on conserved fields. For this purpose, a separate dataset on relative crop yield within areas between two soil conservation bunds was analyzed and the effects of erosion gradient on yield variability/gap were examined. We used long-term yield data collected from ex-Soil Conservation Research Program (SCRP) dataset (CAHA database) in five experimental watersheds (Anjeni, Andittid, Maybar, Gununo, and Hundelafto). The five ex-SCRP watersheds are among the seven watersheds representing different agro-ecologies that are established since the early 1980s to monitor the impact of watershed interventions The database included 3–18 years (duration between 1985 and 2007) of yield data for nine cereal and pulse crops. The data consisted of annual yield data on three positions: below bund ("c"), middle of two bunds ("b"), and above bund where there is sediment accumulation ("a"). For each bund position, annual yield observations were used to evaluate yield gap/variability along three erosion zones between bunds. Sediment accumulation zone ("a") is considered as relatively potential in soil status and soil moisture conditions and the middle zone ("b") an optimal condition regarding erosion-related yield variability between bunds. Thus, we compared the yield between "a" and "c" to determine the potential yield gap/variability. Also, we compared "b" and "c" to examine the optimum yield gap/variability induced by soil erosion processes within successive bunds. To determine on-site yield gaps on conserved lands, the mean percent yield gap between bund positions (i.e., "a" and "c" as well as "a" and "b" positions) was estimated for different crop types.

2.4. Statistical data analysis

We conducted a review analysis of plot-level studies on the effects of LMP and land cover types on soil loss and crop yield

Table 2
The number of field experiments and observations reviewed for soil loss rates and crop yield by categories of SLM practices.

Database variable	Categories of LMP and land cover types	Number of experiments	Number of observations	% of observations
Change in soil loss	Annual cropland cover	10	57	24.2
	Area closure	3	16	6.8
	Agronomy	9	29	12.3
	Drainage	4	18	7.6
	Mechanical erosion control	15	95	40.2
	Perennial vegetation cover	5	21	8.9
	Total	***36***	***236***	***100.0***
Rates of soil loss	Annual Cropland cover	11	13	7.7
	Area closure	2	3	1.8
	Agronomy	9	27	16.0
	Drainage	5	21	12.4
	Mechanical erosion control	16	61	36.1
	Perennial vegetation cover	5	20	11.8
	Control practices		24	14.2
	Total	***48***	***169***	***100.0***
Crop yield	Annual cropland cover	3	3	2.7
	Agronomy	15	63	56.8
	Drainage	5	12	10.8
	Mechanical erosion control	11	33	29.7
	Total	***34***	***111***	***100.0***

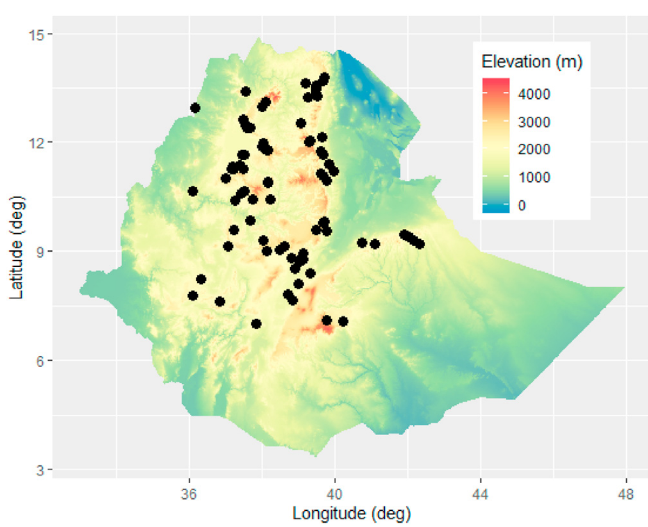

Fig. 1. Map of study locations included in the review.

compared to control practices. The database was organized using the predefined template in Microsoft Excel. The effects of LMP on soil loss and crop yield sets of data from field plot experiments were analyzed for both the specific land management practices and for aggregated categories of LMP (annual cropland cover, drainage practice, agronomy, perennial vegetation cover, area closure, and mechanical erosion control practices) as there were differences in the characteristics and functions of practices. Using data analysis tools in Excel relative mean differences (i.e., in terms of percent changes in soil loss and crop yield) were estimated to evaluate the mean effect of categories of LMP and land cover types against control practices.

3. Results

3.1. Database description

Our review results in 236 entries (36 experiments) of data on effects of LMP and land cover types on soil loss relative to control practices; 169 entries of data on soil loss rates of individual land

Table 3
The number of crop yield observations measured in the area between bunds from five ex-SCRP watersheds.

Watershed	Crop	N	# years	Watershed	Crop	N	# years
Anjeni	Barley	765	17	Hunde-lafto	Barley	236	8
	Wheat	369	18		Wheat	109	7
	Linseed	173	12		Horse bean	203	8
	Horse bean	177	11		Field pea	131	7
	Teff	629	18		Lentil	60	7
Andittid	Barley	1554	19		Maize	317	7
	Wheat	194	19		Sorghum	637	8
	Lentil	60	12		Linseed	11	2
	Horse bean	45	11	Maybar	Barley	1714	18
	Field pea	22	3		Emmer Wheat	251	16
	Linseed	304	18		Wheat	558	17
Gununo	Barley	256	7		Lentil	195	14
	Wheat	21	4		Field pea	470	16
	Field pea	143	5		Horse bean	1007	16
	Horse bean	62	5		Teff	497	18
	Teff	264	7		Maize	1131	17
	Maize	201	5				
	Sorghum	30	3	**Total observations**		**12,796**	

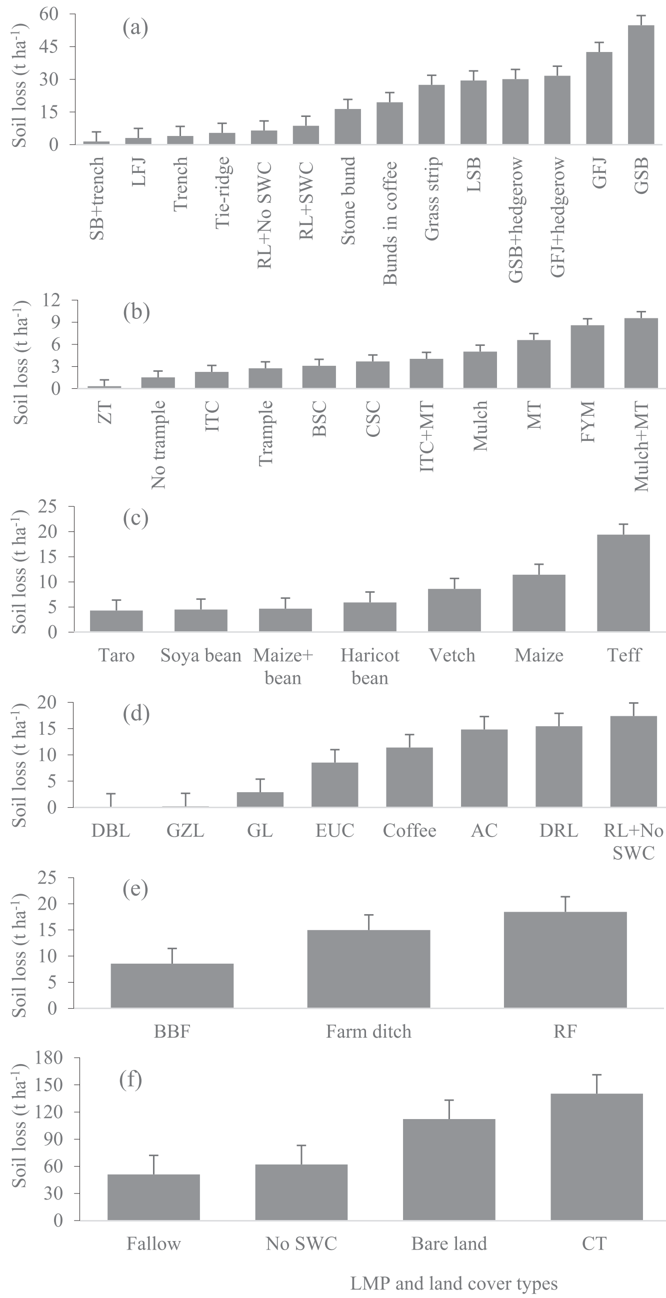

Fig. 2. Average soil loss rates measured under the management of: a) mechanical erosion control practices, b) agronomic practices, c) annual cropland cover types, d) perennial vegetation cover types, e) drainage methods, and f) control practices. SB=Soil bund, LFJ = Level Fanya juu, RL = Rangeland, SWC= Soil and water conservation, LSB = Level soil bund, GSB = Graded soil bund, GFJ = Graded Fanya juu, ZT = Zero tillage, ITC=Intercropping, BSC=Buffer strip cropping, CSC=Contour strip cropping, MT = Minimum tillage, FYM=Farm yard manure, DBL = Degraded bushland, GZL = Grazing land, GL = Grassland, EUC = Eucalyptus, AC = Area closure, DRL = Degraded rangeland, BBF=Broad bed and furrow, RF = Ridge and furrow, CT=Conventional tillage, LMP = Land management practices.

management practices without comparison with control practices (48 experiments); and 111 entries (34 experiments) on effects of LMP and land cover types on crop yield. All entries of the data were categorized into six groups of LMP and land cover management (Table 2). The overall dataset from review studies represented moist (50.6%), sub-moist (35.8%), and sub-humid (11.1%) agro-ecologies (Fig. 1). Also, from five ex-SCRP stations, a total of 12,796 location-crop-year yield data from each of the three erosion zones between bunds were organized (Table 3). Considering all review studies, the largest number of studies and observations were obtained on the implementation of mechanical erosion control practices constituting 40% (95 out of 236) and 36% (61 out of 169) of the total records of change in soil loss and soil loss rates, respectively. Studies on annual cropland cover (24% and 7.7%) and agronomic techniques (12% and 16%) constitute the next largest number of observations of change in soil loss and soil loss rates (Table 2). Drainage, area closure, and perennial vegetation cover practices constitute a small number of studies and observations. A large number of observations on crop yield represented conservation agriculture practices (57%) followed by mechanical erosion control practices (30%).

3.2. Effects of LMP and land cover on soil erosion rates

3.2.1. Soil loss rates

Soil loss results of plot-level studies have been analyzed to understand their comparative erosion control efficiencies. As displayed in Fig. 2, a range of average soil loss of 0.5–55 t $ha^{-1}y^{-1}$ has been measured on fields treated with various conservation practices. Whereas we found an average soil loss rate of 50–140 t $ha^{-1}y^{-1}$ (maximum up to 220 t $ha^{-1}y^{-1}$) on control or conventional practices such as badland, bare land, fallow, and conventional tillage practices. Of the total reviewed studies of the effects of LMP on soil loss (excluding control practices), soil loss rates <10, 10–20, 20–30, 30–40, 40–50 and > 50 t $ha^{-1}y^{-1}$ represent 54.4%, 18%, 6.7%, 10%, 4% and 6.7% of the total observations, respectively (Fig. 2). Out of the results of review studies 55% and 80% of observations of effects of LMP gave soil loss rates below 10 t ha^{-1} and 30 t ha^{-1}, respectively while average soil loss from control practices was 91 t ha^{-1} (Table 4).

Within each category of the LMP and land cover types, individual practices showed variable performances. Soil loss rates within the tolerable limit (2–18 t ha^{-1}y-1) defined by Hurni (1985) were observed in fields treated with the majority of the studied practices. Below 10 t $ha^{-1}y^{-1}$ soil loss rates have been measured from annual cropland covers (except tef crop cover), agronomic practices, moisture conserving mechanical structures like a trench, level Fanya juu and tie-ridge, and grassland among perennial vegetation cover practices (Fig. 2). Erosion rates of 10–20 t $ha^{-1}y^{-1}$ were obtained from the drainage practices on Vertisols, area closure management practices, and non-cropland vegetation cover types (Fig. 2). Among mechanical erosion control practices, level bunds and stone bunds combined with trenches reduced soil loss below tolerable rate (<10 t $ha^{-1}y^{-1}$) while grass strip, stone bunds alone, graded soil bund, and Fanya juu integrated with vegetative hedgerows (see Fig. 6) recorded moderate (15–30 t ha^{-1} y^{-1}) soil loss rates. Significant soil losses (above 40 t $ha^{-1}y^{-1}$) were obtained from graded bunds without vegetative reinforcement (Fig. 2). On the contrary, relative to the treated fields, nearly 65% of the control practices (bare land, fallow, conventional tillage, without any erosion control measures) caused soil loss rates above 50 t $ha^{-1}y^{-1}$. Consequently, it is realized that soil loss rates beyond the tolerable limit have been recorded frequently on lands with no vegetative and agronomic practices.

Among the categories of LMP and land cover types, the order of magnitude of erosion control efficiency decreased from agronomic, annual cropland cover, perennial vegetation management, drainage practices, and mechanical erosion control practices. Average erosion rates of LMP were 4.3 (agronomy), 8.0 (perennial vegetation cover), 8.4 (annual cropland cover), 14.0 (drainage), 14.8 (area closure), 22.6 (mechanical erosion control), and 91.4 t $ha^{-1}y^{-1}$ (without LMP practices) (Table 4). The ranges of soil erosion rate of

Table 4
Average soil loss rate and change in soil loss for the different categories of LMP and land cover types.

	Soil loss rate (t ha^{-1})			Change in soil loss (%)		
LMP and land cover type	N	Mean	SE	N	Mean	SE
Perennial vegetation cover	20	8.0	1.40	21	69.0	5.56
Annual cropland cover	13	8.4	1.24	57	63.5	2.48
Agronomy	27	4.3	2.88	29	66.2	6.09
Drainage	21	14.0	1.84	18	39.8	2.62
Area closure	3	14.8	12.76	16	74.3	4.58
Mechanical erosion control	61	22.6	4.29	95	66.2	1.91
Control	24	91.4	13.07	–	–	–
Mean/Total	**169**	**19.2**	**5.4**	**236**	**64.3**	**3.88**

control practices were between 50 and 140 t ha^{-1}y^{-1} (Fig. 2).

3.2.2. Change in soil loss

The rate of on-site soil loss reduction by LMP and land cover types have been assessed by reviewing 236 pairs of observations against the respective control practice. Table 4 and Fig. 3 present the mean soil loss changes from six groups of LMP and land cover types. Depending upon their nature, structural design and layout specifications, the different categories of practices have shown different soil erosion control efficiency. A mean effect of 60–75% soil loss reduction was recorded from land management practices and land cover types including area closure, perennial vegetation cover, annual cropland cover, agronomic and mechanical erosion

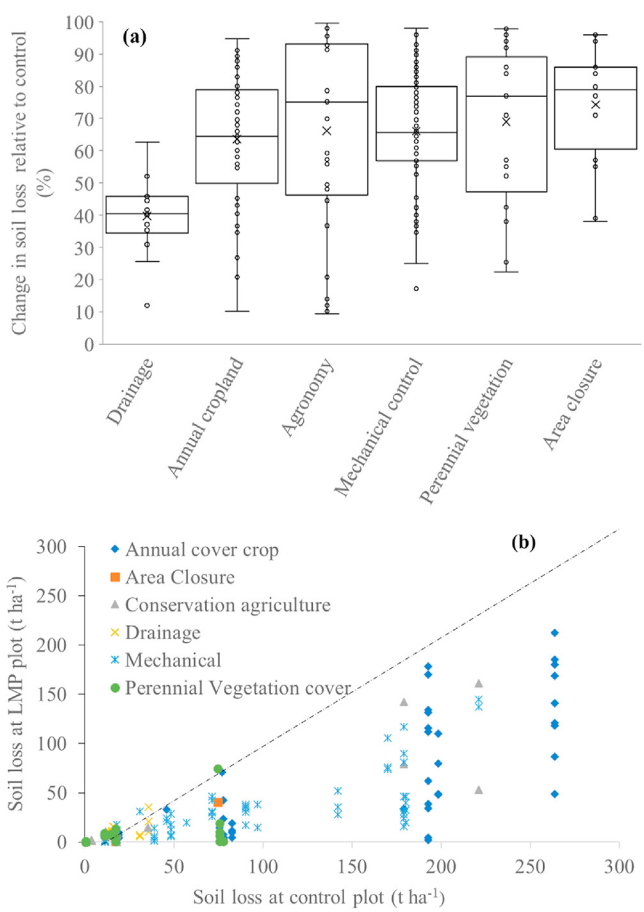

Fig. 3. Box plot of soil loss rates of land management practices relative to soil loss of control practices (a) and relation of soil loss at land management plot and soil loss at control plot (b) for the groups of land management and land cover types.

control interventions. Practices with less intensity of crop covers such as teff, wheat, and faba bean-managed under contour tillage reduced soil loss by 35–65% compared to maize cover (more than 80% reduction). There was a contrasting effect of soil loss reduction between tillage management practices and cropping systems. Minimum tillage management practices reduced 25–50% of the soil loss relative to conventional tillage. On the other hand, cropping systems such as intercropping, buffer strip cropping, contour cropping, and mulching reduced soil loss by a range of 75–90% compared to mono-cropping, fallow, and bare cover practices. Perennial vegetation cover types and area closure management showed 75–90% soil loss reduction. The effectiveness of mechanical erosion practices ranges from 40 to 90% soil loss reduction. Among other mechanical conservation structures, tie-ridges, trenches, level bunds, and graded bunds integrated with trenches and vegetative hedgerows have resulted in 70–90% soil loss reduction, and graded soil and stone bunds reduced 60–70% of soil loss when compared with respective control practices (Fig. 3). Drainage methods reduced soil loss on average by 40–45%.

Overall, we found that soil loss reduction due to LMP and cover types was associated with practices that entail a continuous presence of soil cover during the rainy season, perennial vegetation system, and runoff water retaining structures as barriers for sediment transport. These changes in soil loss also point to modification of slope length and slope factor (Rieke-Zapp & Nearing, 2005) and changes in soil hydrologic properties (infiltration and porosity) as annual cover crops, perennial vegetation, and agroforestry practices have a role to improve infiltration (Basche & DeLonge, 2019). We conclude that these positive changes in soil loss imply the need to integrate and combine the different practices to achieving a significant reduction of on-site soil erosion to a tolerable level and leading to a sustainable best bet practice.

3.3. Impact of LMP and land cover on crop yield

3.3.1. Effects of LMP on crop yield improvement

The review studies revealed a positive yield response (47.5 ± 54.3%) of applying LMP and land cover interventions. However, the rate of increase varied on the nature and type of LMP and land cover types (Fig. 4). Mechanical erosion control, agronomic, and drainage practices increased crop yield by 75.4 ± 54.3%, 37.5 ± 27.9%, and 25.2 ± 14.9% over the control, respectively. Overall, there were 1.3–1.6 times more crop yield increase by applying LMP and land cover interventions over the control practice. Among all the practices, tie-ridge could increase crop yield by more than 200% and mulching with red ash in the dry environment could also increase yield by 120% (Fig. 4). Applying trapezoidal bunds, fanya juu combined with grass hedgerow, tie-ridge, contour ridges, deep tillage, mulching, green manure, and alley cropping increased crop yield by more than 40% (40–120%). Stone bund, soil bund, conservation tillage techniques (green manure, zero/minimum tillage, open ridge), and intercropping showed a small range of yield increase (25–30%). However, grass strips showed no positive effect on crop yield change which is like results reported by Herweg and Ludi (1999). Despite there was a general trend in crop yield increment across all crop types, the effects of LMP on the rate of crop yield improvement varied from crop to crop. The average positive crop yield response was high for sorghum (75%), chickpea (54%), and lentil (40%). About an 18–30% yield increase was recorded for other crops (faba bean, sesame, wheat, teff, and maize). In some field experiments where minimum tillage and zero tillage were applied in low rainfall areas, there was a negative yield response of maize and wheat yield.

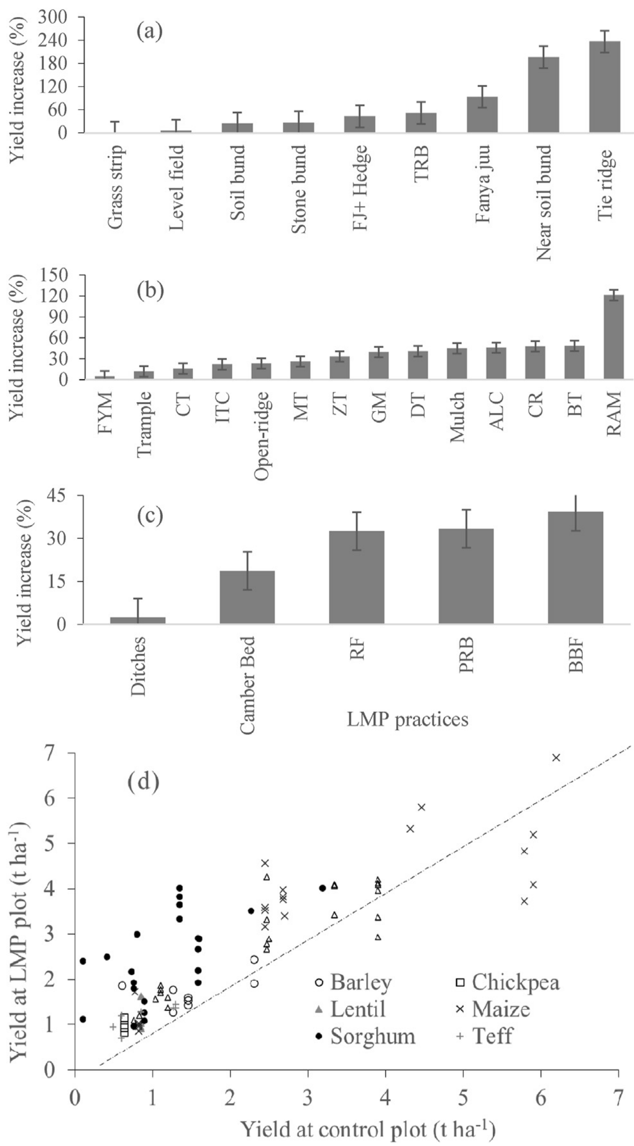

Fig. 4. Percent crop yield increases of groups of LMP: a) mechanical erosion control practices, b) agronomic practices, c) drainage practices, and d) relation of yield at LMP plot and yield at control plots by crop types. FJ= Fanya juu, TRB = Trapezoidal bund, ZT = Zero tillage, CT=Contour tillage, ITC=Intercropping, MT = Minimum tillage, GM = Green manure, DT = Deep tillage, ALC = Alley cropping, CR=Contour ridge, BT=Berken tillage, RAM = Red ash mulch, FYM=Farm yard manure, BBF=Broad bed and furrow, RF = Ridge and furrow, PRB=Permanent raised bed.

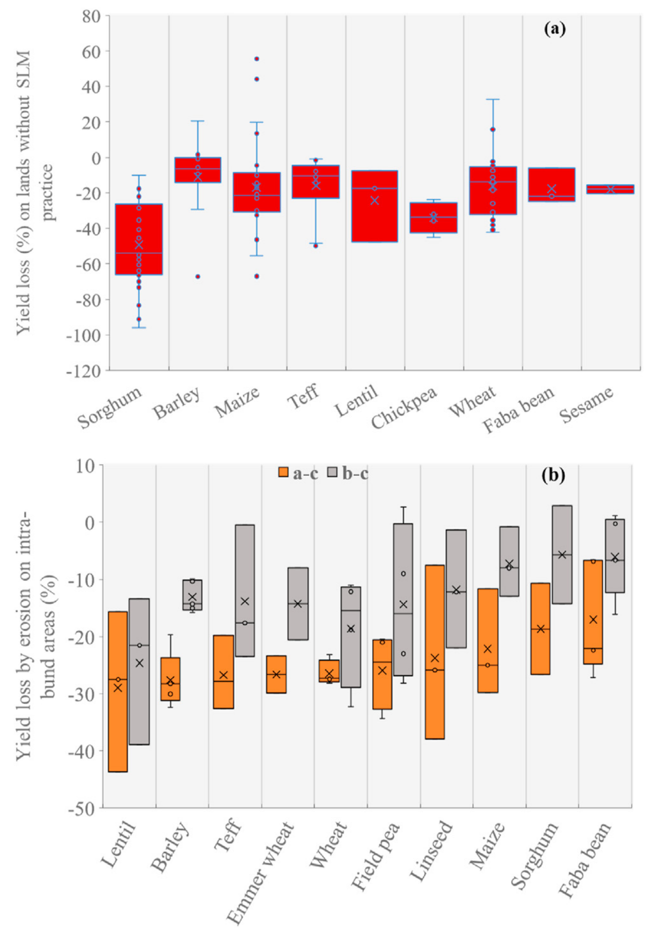

Fig. 5. Percent yield loss by crop types: a) induced under without land management practice, and b) induced by erosion gradient on conserved areas between bunds. a-c represents yield loss between above bund (accumulation zone) and below bund (erosion zone); b-c represents yield loss between middle of bund (intermediate zone) and below bund (erosion zone).

3.3.2. Yield loss due to soil erosion

Fig. 5 presents the average yield loss for different crops with and without LMP practices. The average yield loss on fields without LMP was 26.5 ± 26.0% (Fig. 5, top) compared to conserved fields with appropriate practices. Maximum yield loss was estimated for the two dryland crops, sorghum (49.4 ± 23.4%) and chickpea (34.1 ± 8.9%) which likely attributed to both soil erosion and moisture stress constraints. The average yield loss for crops growing in moist and sub-humid areas was 24.3 ± 20.9%, 17.7 ± 10.2%, 16.8 ± 28.9%, 16.1 ± 18.1%, 16.0 ± 18.0%, and 11.0 ± 23.1% for lentil, faba bean, maize, wheat, teff, and barley, respectively (Fig. 5, top). However, it must be noted that the number of review studies (<5) for chickpea, lentil, and faba bean is small and may not enough to generalize the results on yield loss without land management practice. Previous national scale studies reported a very low estimate of a decline of crop yields by soil erosion, by 1.5% (Ellis-Jones & Tengberg, 2000) and 1–2% per year (Hurni, 1993). A modeling approach was applied to evaluate the impact of water erosion in Ethiopia and reported a range of potential reduction of 10–30% crop yield by 2030 (Sonneveld and Keyzer, 2003). Due to the occurrence of high soil erosion and nutrient depletion, the yield loss in this study is more than the anticipated 16.5% yield reduction in Sub Saharan Africa by 2020 and 13% estimate globally (Lal, 1995). A recent study on global market impacts of soil erosion assumed a mean crop productivity loss of 8% in arable lands threatened by severe erosion (>11 t ha^{-1} y^{-1}) (Sartori et al., 2019). Based on the measured field evidence collated in this study, the previous research reports underestimated the productivity loss by water erosion in the tropical and sub-tropical conditions. This leads to undermining the negative impacts of land degradation on the economy of smallholder agriculture in Ethiopia and leads to misguided decisions on the responses of sustainable land management investments.

It is also understood that maximum yield cannot be achieved even on conserved fields due to the inevitable yield loss because of a continued soil erosion gradient. We found that crop yield variability/gap in conserved fields is apparent. As presented in Fig. 5 (bottom), the crop yield difference between the different levels of erosion zones, i.e., between the lower side of bund (“c”) and sediment accumulation zone immediately above the bund (“a”) was

Fig. 6. Pictures of commonly applied land management practices: a) graded soil bund (ditches on upper side to discharge runoff), b) graded soil bund with vegetative hedgerows, c) graded Fanya juu (ditches on lower side), d) stone faced soil bund, e) stone terrace, and f) bench terrace.

very high. On average, 25 ± 3.7% (range of 19–29%) yield reduction was measured at the erosion zone compared to the sediment accumulation zone. There was a yield decline by 13.5 ± 6.1% (6–25%) between the erosion zone ("c") and the middle zone ("b"). The yield loss induced by soil erosion gradient on conserved bunds has shown a distinct difference between early planting and late planting crops. Those crops with less density of cover during the early rainfall period and very fine and smooth surface roughness conditions showed high yield loss compared to crops with good crop cover. For example, yield loss was high for lentil, wheat, barley, teff, field pea, and linseed. Whereas, low yield loss was measured on maize, faba bean, and sorghum fields where there is a significant density of surface cover during the early rainfall period. In general, yield loss ranges 20–30% between erosion zone and accumulation zone, and 5–25% between erosion zone and middle zone (Fig. 5, bottom). Other studies also described the differences and non-uniform yield at the upper and lower side of bunds (Alemayehu et al., 2006; Vancampenhout et al., 2006). This yield variability or gap was likely created due to the process of soil erosion and deposition and moisture storage in the area between bunds. For example, a study in Anjeni revealed that higher yield on the accumulation zone is attributed due to 55–75% sediment deposition on the upper side of bunds (Subhatu et al., 2017).

4. Discussion

The results of this review in many ways corroborates with previous review studies in Ethiopia. A review study in Sub-Saharan Africa (Wolka et al., 2018) found a more or less similar positive effect of tie-ridge, soil bund, and stone bund on soil loss change, where a range of 40–80% soil loss change was achieved when compared to control practices. Others reported a 50–70% reduction in soil loss by soil bund, stone bund, fanya juu, and integrated measures (Abera et al., 2020; Adimassu et al., 2017; Amare et al., 2014). It is reported that agronomic practices could also reduce up to 45% of soil loss (Wolka et al., 2018). It was reported that agronomic and vegetative practices contributed to the prevention and reduction of land degradation and their combination can restore degraded lands (Abera et al., 2020; Kassawmar et al., 2018). Similarly, in the semi-arid condition in Italy, vineyard farming under conventional tillage is known to be responsible for high soil erosion rates. However, cover crop soil management practices significantly reduced the erosion rates by 80% (from 35.5 to 7.2 t ha^{-1} y^{-1}) of the vineyard farm with similar characteristics (Novara et al., 2021). The combined use of cover crop soil management and minimum tillage operations further reduced the soil erosion rate to 4.7 t ha^{-1} y^{-1} (Novara et al., 2019). A study on the synthesis of plot soil loss data in Europe (Maetens et al., 2012) reported that bare soil, cropland, fallow, and semi-natural vegetation cover resulted in 10–20, 6.5, 5.8, and <1 t ha^{-1} y^{-1}, respectively. The results of the study using land-use combinations in the hillslopes of the Loess Plateau of China show that soil erosion rates are decreasing in the order of cropland, orchard, grassland, and forestland (Fu et al., 2009). The implication to this is the need to give priority to agronomic, conservation agriculture, cropland covers, and perennial vegetative measures as well as a combination of mechanical conservation measures with vegetative measures wherever necessary to break the slope and retard runoff velocity.

About yield response to LMP, the previous review works in Ethiopia reported mixed effects of soil conservation techniques on crop yield. (Wolka et al., 2018) reported that about 80% of the review studies in Sub-Saharan Africa indicate a positive effect on crop yield. Adimassu et al. (2017) reported that only 10–30% of the observations of level soil bund, level fanya juu, graded fanya juu, and graded soil bund resulted in a positive effect on crop yield. They claimed waterlogging and land lost by the structures as factors for yield reduction. According to meta-analysis results of soil loss by Abera et al. (2020), physical structures like fanya juu and soil bunds alone did not show a significant positive effect on productivity. Herweg and Ludi (1999) found that fanya juu, soil bund, stone bund, and grass strips did not increase crop yield and biomass production in the highlands of Ethiopia. In-depth analysis of the review studies that reported a decline in crop yield indicates that the decline was associated with experimental conditions with very shallow soil depth and poor soil fertility, and fields characterized with Regosols and prolonged waterlogging problems (Adimassu et al., 2017; Hengsdijk et al., 2005). Moreover, some of the inconsistent effects of physical conservation practices on crop yield may be likely related to a small number of observations included in the analysis.

On the other hand, previous studies reported a positive effect of conservation agriculture and agronomic practices on crop yield (Adimassu et al., 2017; Wolka et al., 2018). Most agronomic practices resulted in a crop yield increase by 20–25% (Abera et al., 2020; Adimassu et al., 2017). Tie-ridge, which is practiced under low rainfall areas and among the most frequently reported practice significantly increased crop yield (Abera et al., 2020; Wolka et al., 2018). This high rate of yield increase is likely due to the moisture conservation effect where such practices most prevail under arid conditions (Araya & Stroosnijder, 2010; Erkossa et al., 2018). However, in soils with low infiltration rates and high rainfall areas, moisture conserving practices like tie-ridging depending on the soil types harming yield (Belay et al., 1998). A combination of techniques such as bunds with vegetative hedgerows, improved tillage with mulching, bunds with moisture conservation techniques, and crop rotations further enhance crop yield (Abera et al., 2020; Lanckriet et al., 2012) due to their complementarity benefits. This is also demonstrated in our results, as shown in Fig. 4.

A further look at the results of this review suggests that compared to previous review studies, these findings draw markedly different conclusions on the benefits of LMP. The entire review studies revealed a positive yield response and on average 47.5% yield gain can be achieved by implementing different types of land management practices. Overall, on average 25–75% of crop yield benefits can be boosted by investing in different types of land management practices. This means that specific agronomic, moisture conservation, and runoff erosion control practices that involving more sediment storage capacity, on-site moisture conservation capacity, and improved tillage characteristics and crop cover intensity was most effective in increasing crop productivity. There is a piece of growing evidence that increases in nutrient accumulation and moisture retention through increased use of agronomic and conservation agriculture systems and combination of mechanical structures with vegetative techniques are associated with increased yield stability (Abera et al., 2020; Basche & DeLonge, 2019; Erkossa et al., 2018). The productivity gain was much pronounced relatively on dryland conditions (e.g., sorghum (75%) and chickpea (54%)) indicating the likely role of management practices for moisture conservation along with soil loss reduction to enhance ecosystem services.

This synthesis discovered that land management practices greatly contribute to improving ecosystem services –reduced soil loss and increased productivity. High soil loss reduction was achieved by using practices with better vegetative cover as they play the role of preventing rainfall and water erosion impact. Better yield increases however mainly related to practices characterized by high moisture and sediment retention capacity, including mechanical erosion control and conservation agriculture practices. A comparison of categories of land management practices, particularly on croplands, indicated both provisioning and regulating ecosystem functions can be achieved by applying mechanical erosion control and conservation agriculture practices. Regulating ecosystem functions is further enhanced when different categories of practices are applied in combination. These results confirm the presence of best bet alternative land management practices that enhance ecosystem services. The best bet practices are associated mainly with those practices characterized by their retention capacity of both moisture and sediment, presence of continuous cover, improvements in the soil hydrologic properties, and synergistic effects of multiple management practices. The comparison of land management practices suggests that appropriate selection of an effective combination of practices under different environmental conditions is found necessary to prevent and reduce the impact of land degradation, maintain a long-term soil health system, and adapt to rainfall variability and climate change. The consequences of inaction and/or inappropriate selection and targeting of practices to adapt to a specific condition leads to significant yield loss for land users and leading them to low economic capacity to respond to their food insecurity. Such costs of inaction incur not only direct economic loss to farmers but also incremental negative impact over years that lead to reducing the capacity for sustainable land production and resilience to shocks under changing climate and drought. This implies that a strong push in the dissemination and adoption of cover management and in-situ moisture conservation practices in combination with mechanical erosion control practices is needed to prevent and reduce land degradation and negative economic impact as well as to enhance multiple ecosystem benefits, sediment management, and productivity. Overall results revealed that the effects of LMP and land cover types must be widely studied under different agro-climatic settings. This review confirms that LMP and land cover types are alternative options to reduce erosion rates and change degraded lands and unsustainable agricultural management into long-term sustainable management strategies. The role of LM and LC practices needs to be considered for achieving sustainable solutions (multiple ecosystem services) and then contribute to the land degradation neutrality.

5. Conclusion

This synthesis forms a review of 118 plot-level soil loss and crop yield studies (520 observations) and a long-term fixed plot dataset. The review gain insight into the positive performance of land management practices and land cover types in reducing soil loss and increasing crop yield. The greatest benefits on the reduction of soil loss were observed with the annual cropland covers, area closures, perennial vegetation cover, and mechanical erosion control practices. The most significant positive impact of conservation agriculture and mechanical erosion control practices on soil loss changes was achieved when they are combined with other land cover management and moisture management practices. Yet, it must be noted that the implementation of commonly practiced mechanical soil conservation structures did not reduce the absolute soil loss rates below tolerable limits. The important finding, unlike previous review studies, is that mechanical erosion control practices and conservation agriculture techniques have significantly increased crop productivity. Although the studied practices show the greatest promise to enhance ecosystem services, the extent of implementation of agronomic and vegetative management practices has not been equally pushed by the extension system as compared to mechanical erosion control practices. The negative impact of the inaction of implementing land management practices and inefficient practices on conserved lands led to a 10–45% yield loss and a 5–25% yield gap between the intra-bunds, respectively. Thus, addressing land degradation risks particularly soil erosion is not only a matter of implementing land management practices but also, the concern is how to increase the efficiency and sustain these practices on conserved areas. The review results anticipated to provide evidence to experts and planners in land restoration to compare, identify, and target best land management practices on their relative effectiveness on soil loss reduction and yield gain. This evidence would lead to guide decisions on the implementation of appropriate and effective and sustainable land management practices at the local level and land restoration investment at the national scale to achieve national LDN targets.

Future implementation of sustainable land management should assess greater opportunities for adopting integrated land cover management and conservation agriculture practices into the agricultural land-use systems. To enable wider scale analysis, long-term replicated studies that consist of both plot and watershed level data would be needed to generate evidence on the broader impact on multiple ecosystem services. Analyzing the interaction of land management practices with other environmental and farming conditions was beyond the scope of this paper and open for future study. Thus, additional research is needed to update the database and build broader scale evidence, and then better understand what conditions the land management practices are more adaptable and effective to facilitate targeting.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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