Implication of Long-Term Terracing Watershed Development on Soil Macronutrients and Crop Production in Maybar Subwatershed, South Wello Zone, Ethiopia

Authors: Taye, Tilahun, Moges, Awdenegest, Muluneh, Alemayehu, Lebay, Muluken, and Abiye, Wudu

Source: Air, Soil and Water Research, 14(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/11786221211004220

Implication of Long-Term Terracing Watershed Development on Soil Macronutrients and Crop Production in Maybar Subwatershed, South Wello Zone, Ethiopia

Air, Soil and Water Research
Volume 14: 1–12

DOI: 10.1177/11786221211004220
SAGE

Tilahun Taye[1], Awdenegest Moges[2], Alemayehu Muluneh[2], Muluken Lebay[1] and Wudu Abiye[1]

[1]Sirinka Agricultural Research Center, Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia. [2]Hawassa University, Hawassa, Ethiopia.

ABSTRACT: Long-term watershed management in Ethiopia was evaluated in various agro-ecologies starting in the 1980s. Our research was carried out to investigate the effects of long-term watershed management on soil macronutrient status and crop production in the Maybar sub-watershed terrace positioning system, which has a long-term data set on various aspects, such as hydroclimatology, agriculture, and social studies. Crop yield data were collected from 40 fixed plots of that data set, and soil samples were collected by topo-sequencing of the catchment from the cultivation field based on different terrace position plot arrangements. The results showed higher crop yield and production of biomass in the upper section or deposition zone of soil and water conservation structure than below the structure or loss zone, but did not vary significantly from the annual production potential. The annual production of cereals was marginally decreased, but not pulse crops, reducing the wheat harvest production from the middle to the loss zone (23.8%) rather than the deposition zone to middle portion of the terrace (8.0%). In comparison, to increase the slope position of the terrace, the redaction percentage of pulse crops (field pea and lentil) is greater, because in the first terrace location (upper to middle) and in the second terrace, the output capacity of field pea was reduced by 22.4%. The condition of soil fertility between the 2 consecutive systems for soil and water protection differed from the upper to the lower land positions. Improvement in soil chemical and physical properties relatively increased toward the upper land position. Soil organic matter, available phosphorus, bulk density, and soil moisture content were significantly affected by soil and water conservation structures ($P \leqslant .05$). Long-term terrace growth typically has a positive effect on improvements in onsite soil resources and the capacity for crop production. It therefore has a beneficial impact on onsite natural resources, such as enhancing soil macronutrients and increasing productivity in crop yields.

KEYWORDS: Watershed management, terrace, soil fertility, crop production, Maybar

RECEIVED: September 24, 2020. **ACCEPTED:** March 1, 2021.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: They helped me during data collection and encoding. The authors thank Amhara Agricultural Research Institute, in general, and Sirinka Agricultural Research Center, in particular, for providing funds. Special thanks also goes to the water and land resource center project of Ethiopia for providing with the necessary data; furthermore, the greatest thanks also goes to Dr Gete Zeleke (General Director of the project) for the financial support to most expenses.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Tilahun Taye, Sirinka Agricultural Research Center, Amhara Regional Agricultural Research Institute, Bahir Dar, p.o.box 74, Woldia, Ethiopia. Email: sarctilahun3@gmail.com

Introduction

The historical perspective of watershed management in Ethiopia was nearly the same as other developing countries in Africa. Some evidence indicated that watershed management in Ethiopia started from 1970s.[1] Before the extreme drought of 1972/1973, the need to resolve land degradation in the form of soil erosion issue was recognized, and preparation for watershed creation began in the 1980s following the drought of 1984/1985. It was targeted to improve the rural area's degraded land rehabilitation through conducting soil and water resource conservation–related programs at the watershed.[2]

In Ethiopia, the Watershed Management Program was formally introduced in the 1970s and continued until the 1990s, with a government-led, top-down, and intensive approach.[3] It was more focused on the implementation of initiatives for soil and water conservation, in particular the physical approach.[4] After the early 2000s, integrated watershed managements at the community level were implemented to minimize the depletion of natural resources that causes the loss of land and water resources that have a negative effect on rural livelihoods. It was implemented with including different integrated technologies that improved the livelihood of the community.[5] This encouraged the Ethiopian government to launch an extensive soil and water conservation program.[6,7]

The loss of soil from the land surface is widespread in the Ethiopian highlands and adversely affects the productivity of all natural resources.[8] Conservation schemes were introduced, especially after the occurrence of drought and famines in the 1970s.[9] Starting from the 1970s and onward, the huge area has been taken under the soil and water conservation activities,[10] because in most degraded and step areas terraces were constructed intensively.[11]

The Government of Ethiopia introduced watershed development and management programs starting in the early 1980s with the support of food and agricultural organizations (FAOs) in collaboration with the Ministry of Natural Resources of Ethiopia. It was focused more on natural resource rehabilitation and degraded management of land.[12] In the meantime, the soil conservation research project had established 6 monitoring stations of the multi-scale watershed in the different parts of

Ethiopia. Among these monitoring stations, Maybar is one of them, which accumulated data set in terms of various hydrological, biological, and environmental aspects.[13]Therefore, crop production, hydrosedimentation, and soil samples were obtained. It was achieved as a result of positive impacts on soil fertility, which is a key to ensuring sustainable agriculture by improving soil characteristics such as soil rich in essential nutrients and water storage ability to promote a favorable climate for healthy plant growth. Consequently, the way in which soils are managed has a major impact on productivity and sustainability.[14] Watershed management has also played an important role in rehabilitating degraded land with improved soil fertility status, improved vegetation coverage, and maximized agricultural production.[15,16]

For the last 3 decades, various types of watershed impact studies were done by MSc and PhD students, and government and nongovernmental organizations in Ethiopia. Most of the studies were focused on the hydrologic system process.[13,17,18] Some efforts also were undertaken on soil fertility status and land-use/land cover change, but there are no interaction studies that can be generated from the impact of watershed development on biophysical and productivity aspects such as soil moisture and effect of fertility gradient difference on crop productivity trend.

Therefore, this study was conducted to investigate the value of long-term watershed development about onsite effects of the watershed components with particular focus on crop production gradient and soil macronutrient dynamics in upper, middle, and lower terrace positions. It is important to policymakers regarding natural resource management and also it is powerful to recommend long-term watershed impacts on the beneficiary. The goal of this study was to determine the effects of terrace gradient differences on physical and chemical properties of the soil and to evaluate variations in crop productivity.

Material and Methods

Site description

Maybar is located in the subhumid northeastern part of the central Ethiopian highlands in Southern Wello Administrative Zone (Figure 1). The research stations come from the soil conservation research project's (SCRP) first research site that was established in June 1981. The gauging station is located at 39°40′E and 11°00′N.[19] According to the physical geographic survey, the catchment is characterized by highly rugged topography with steep slopes ranging between 2500 and 2860 m.a.s.l. within a catchment of 116.19 ha area. Slopes range from over 64% to less than 6%.

It receives an average annual rainfall of 1325 mm/y.[20] The annual mean minimum and mean maximum temperatures for the periods from 1999 to 2006 were 11.43 and 21.6°C respectively. It is a bimodal rainfall pattern with erratic distribution.

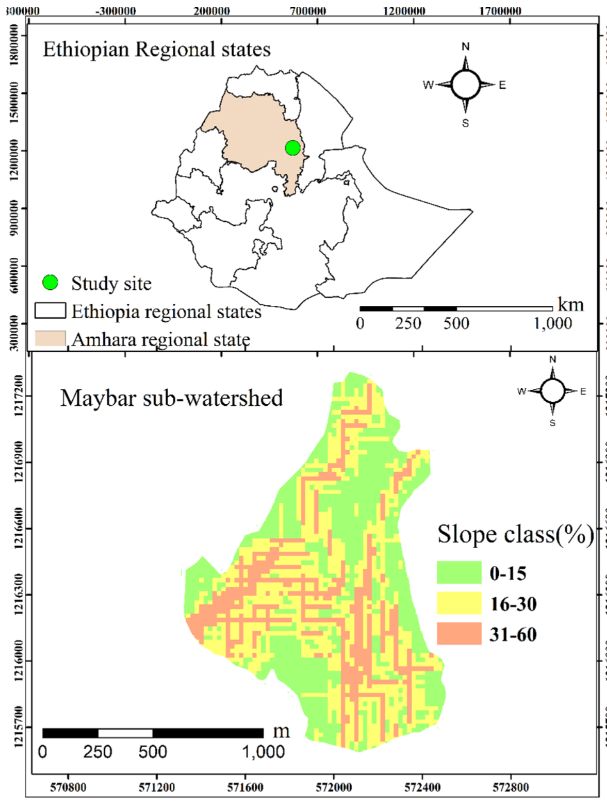

Figure 1. The study site and slope classes (%).

The small rainy season (Belg) occurs from March to May, whereas the main rainy season (Kiremt) occurs from June to September and the dry season from October to February. It is mostly dominated by sandy clay loam covering 80% of the watershed, and the rest is clay loam.[13]

The farming system of the area is mixed, which are crop production and livestock husbandry. Mostly, it depends on rain-fed agriculture, and the major crops are tef, wheat, barley, pulses, and maize on an average landholding of 0.5 to 1 ha per household.

Soil conservation in the form of level soil and stone bunds was introduced in the research catchment between March and July 1983 through a Food-for-Work campaign conducted by the Ministry of Agriculture. Some area closures followed in 1986 when approximately one-tenth of the population of the area was resettled to Wellega, only to return some years later.[13] Small-scale agriculture with a mixture of crops and livestock, fields plowed with oxen, and subsistence production are the most dominant agricultural systems of the area.

It is a moist mid-highlands climatic belt. Based on the evidence of previous studies, around 60% of the catchment was cultivation land and the remain 40% was covered with woodland and grassland in equal proportion.[21] The croplands are generally at the backslope of the catchment, and the grass and woodlands are near the divide of the watershed and on the shallowest soils.[22]

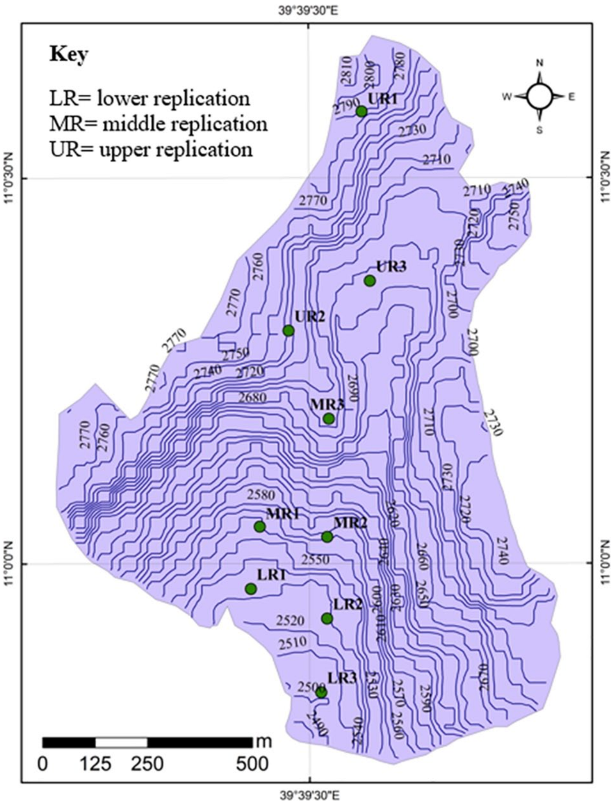

Figure 2. Topo-sequence classification and soil sampling locations.

Study design and soil sampling techniques

Soil samples were collected from the cultivation field by the topo-sequence sampling technique (Figure 2). Therefore, to capture the soil status variability of the whole area, the catchment was predefined into 3 landscape positions (upper, middle, and lower landscape positions). The classification was done through visual interpretation and screen digitization on the 2019 Google Earth pro satellite image and analyzed by ArcGIS 10.3.1 software. The whole catchment was assessed with the support of intensive field observation. Based on vegetation coverage, land use type, slope gradient, and general physical nature of the site, the watershed boundary was divided.

The location of the plots was the same as the previously existing array plots of fixed crop data. Three sampling points identical to the previously fixed plots (between the 2 consecutive terraces) were obtained at each landscape position and were repeated 3 times per site. The plots that were established in the upper catchment cropping rotation history were barley and tef, and in the middle and lower catchment plots, they were maize and tef in the past and present, respectively. In each landscape position, 3 terraces and a total of 9 terraces were considered for this study.

Finally, the sample of similar experimental units with similar replications was mixed together and ready to analyze. The composite samples from each replication were done through the similarity of the terrace slope positions. Hence, replication 1 is the composite of first replication, and replications 2 and 3 are the composite of second and third replications of each landscape position, respectively. The slope gradient of each replication is between 12% and 15%.

To compromise the vertical and horizontal variation of the soil, the replica was established in relatively similar slope positions, and the sample that was taken in one experimental unit was mixed together and taken as 1 treatment.

The sampling depth considered the effective root zone and the maximum root depth of the crops. The maximum root depth from the locally adopted crop types is 80 cm and 1 m for faba bean and maize, respectively.[23]

The soil sampling depths of faba bean were 0-40 cm and 40-80 cm, representing the root zone of crop sowing in the area for soil moisture content determination using an auger[24] and collected separately by the circular-shaped can. Similarly, separate soil samples were taken by sharp-edged steel cylinder (core sampler) for bulk density determination.

On the contrary, from each experimental unit of the topsoil (0-20 cm), composite samples were collected and each composite sample placed was in a plastic bag and labeled carefully with the location, treatment unit, and depth of soil. These samples were taken as soon as the 2019 main crop was harvested around February first week.

Soil physical and chemical property analysis

Soil texture, moisture content, and bulk density were the selected physical soil parameters, which were the most determinant factors of soil fertility status.[25] For soil moisture determination, the gravimetric method was used to know the amount of water content stored in the soil. Soil bulk density was determined by the undisturbed volumetric method after drying the soil samples in an oven at 105°C repeatedly to constant weights.[26]

Soil textural class was also determined by the hydrometric method,[27] which estimates the percentage of sand (0.05-2.0 mm), silt (0.002-0.05 mm), and clay (<0.002 mm) fractions in the soils, after destroying organic matter (OM) using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexametaphosphate ($NaPO_3$) and sodium carbonate (Na_2CO_3).

Major soil chemical properties such as soil organic carbon, pH, total nitrogen, available phosphorus, available potassium, and electrical conductivity (EC) have been determined following the appropriate laboratory procedure and analytical methods (Figure 4). The Walkley and Black[28] wet digestion method was used to determine the soil carbon content the and percentage of soil OM which was obtained by multiplying the percentage of soil organic carbon by a factor of 1.724. Potassium (K) was determined after extracting the soil samples by ammonium acetate (1 N NH_4OAc) at pH 7.0. The pH of the soils was measured in water and potassium chloride suspension in a 1:2.5 soil: liquid ratio.[29] The total nitrogen content was determined using the Kjeldahl method, distillation, and titration[30]

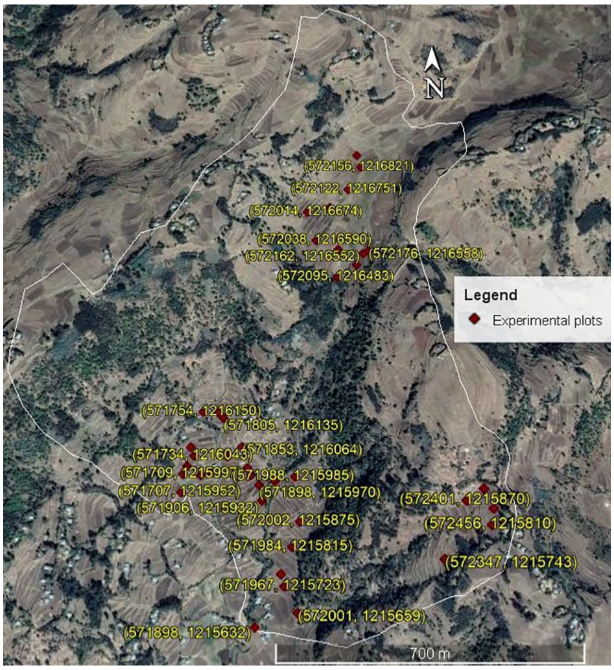

Figure 3. Scheme of the crop data source: Google Maps.

or by oxidizing the OM in concentrated sulfuric acid solution (N H_2SO_4), and the available phosphorus was determined following the Olsen procedure.[31] The Olsen method is the most widely used for phosphorus extraction under a wide range of pH in Ethiopia.[32] The EC of soils was measured from a soil-water ratio of 1:2.5 socked for 1 hour by the EC method.[33]

Data source for crop production analyses

Starting from 1991, 40 fixed experimental plots were established on on-farm cultivation fields which were designed based on soil conservation research project concept and methodology of crop yield and biomass data collection (Figure 3). Between the 2 existing conservation systems, each plot was placed. The plots were placed 3 times between 2 consecutive terraces, directly below the terrace, between the terrace, and near to the 1 m^2 terrace. Both cropping season data were taken and analyzed while the same year's data had been missed. The reason behind these missing data was the crop was harvested by farmers before the appropriate data were taken, fallowing the damage of land and yield by unexpected snow rain.

To determine the catchment-level crop production from predetermined fixed on-farm, experimental data starting from 1991 to 2018 were taken from Sirinka Agricultural Research Center and the Bureau of Water and Land Resource Center on Maybar station Database. The production potential of gradient difference of the land based on each harvested season data was analyzed by the TESTMAIN program[34] and the crop type of each season was interpreted separately. A linear regression was implemented appropriately that management remains the same through the whole years. In addition, the variation of yield and biomass production percentage within the terrace positions were calculated using the following formula:

$$Change(\%) = \frac{\begin{array}{c} Production\ of\ first\ plot \\ -Production\ of\ next\ plot \end{array}}{Production\ of\ next\ plot} \times 100 \qquad (1)$$

Result and Discussion

Implication of soil chemical and physical properties

The variation in soil chemical and physical properties based on the different terrace positioning system was analyzed and presented. In all aspects, indicators of soil fertility status such as soil chemical and physical properties had been decreased vertically within the terrace positions. Each selected parameters had been discussed separately in the following way.

Status of soil chemical properties at different terrace positions. The results of this study showed that the soil pH of cultivation land increased downslope of the terrace position structure (Table 1) numerically, but statistically was not significantly affected by the gradient difference which ranges from 5.91 to 6.01. According to Landon[35] soil acidity standard, it is under a moderately acidic range. On the contrary, available phosphorus at the lower slope was significantly different ($P \leqslant .05$) from the middle and upper slope, as it ranges from 12.35 mg/kg up to 18.65 mg/kg below the structure to the upper structure, respectively.

According to the soil Olsen-P determination, the critical level of phosphorus for optimum crop yield production is between 10.9 and 21.4 mg/kg, above which there is an increase in crop yield response of soil Olsen-P.[36] Available soil P level of <5 mg/kg is rated as low, 5 to 15 mg/kg as medium, and >15 mg/kg as high.[35] The available P of the soils of the study area below the structure and in the middle of the structures is under medium range and immediately above the structure is under high range.

The OM content of agricultural topsoil is usually in the range of 1% to 6%,[37] and according to the soil OM level classification of Landon[35] and Mamo and Haque,[32] the soil fertility status of Maybar was under the range of very low to low (0.99%-1.85%).[38] Currently, ranges relatively exceed the medium levels, which range from 2.13% to 2.56% at the below structure to the lower part of the structure, respectively.

According to Gebeyaw,[38] the chemical and physical properties of the Maybar watershed soil were affected by different land use and management types but he did not answer the gradient variation of the terrace position. He also stated that a lower pH value in cultivated land was attributed to a high rate of OM oxidation which is important to produce organic acids and provide hydronium ion solution in the soil, which can reduce the pH value of the soil. It also in line with other studies. Hence, according to the study of variation in soil chemical properties in topo-sequence in an arid region, soil pH was

Table 1. Effect of soil and water conservation structure on major soil chemical properties in Maybar subwatershed.

TREATMENT	PH (H_2O)	EC (DS/M)	OM (%)	TN (%)	AVA. P (MG/KG)	AVA. K (MEQ/100 G
Below slope position	5.91	0.03	2.13[b]	0.19	12.35[b]	0.69
Middle slope position	5. 5	0.04	2.20[ab]	0.21	13.58[b]	0.81
Upper slope position	6.01	0.04	2.56[a]	0.24	18.65[a]	0.89
Grand mean	5.81	0.03	2.3	0.21	14.86	0.79
CV	2.63	37.67	9.90	24.24	14.06	28.39
Lsd	ns	ns	*	ns	*	ns

Abbreviations: EC, electrical conductivity; TN, total nitrogen; OM, organic matter.
The main effect means within a range followed by the same letter are not significantly different from each other at $P \leqslant .05$.
ns, nonsignificance ($P > .05$); *significant ($P \leqslant .05$).

increased with increasing soil depth along the incline due to carbonate content of the soil, and high intensity of rainfall and lower pH value in cultivated land were attributed to a high rate of OM oxidation.[39]

Most of the soil nutrients significantly decreased due to soil erosion and landscape features with increasing slope steepness and unwise utilization of land.[40] The deposition of sediment on the lower slope has had a noticeable effect on the soil's physical and chemical properties.[41] Soil bunds reduce runoff, as well as soil and nutrient losses and organic carbon loss from cultivated lands.[42]

The terrace positioning system on EC, total nitrogen (TN), and available potassium (K) was not significantly different at $P \leqslant .05$. But numerically it fluctuates from the lower terrace to the upper part of the terrace since EC varies from 0.03 to 0.04 dS/m, TN from 0.19% to 0.24%, and K from 0.69 to 0.89 mEq/100 g from the lower to the upper part of terrace position. This result indicated that most soil chemical properties were affected by the gradient difference of the land which may be developed from the implemented terrace structures. The result agrees with various studies, as in all land-use systems most soil chemical properties such as OM, available phosphorus, total nitrogen soil pH, and soil EC had been decreased upward the slope.[40,43] The terrace positions could affect the variability of soil properties and improve productivity.[44,45] The study also conducted in soil and water conservation measures on most soil properties in northern highlands of Ethiopia indicates that soil resource management practices had a significant difference value on key soil physical and chemical properties.[46]

Status of soil physical properties at different terrace positions. The nature of the soil texture is under clay loam class, and the values of the clay, sand, and silt textural class were not significantly varied. In contrast, bulk density could be significantly ($P \leqslant .05$) affected by these terrace positions. It ranges from 1.48 up to 1.23 g/cm^{3}from the lower to upper terrace positions which is under well-aggregated soil condition. It argues with the previous studies conducted in that area, the result of which was bulk density was significantly affected by the terrace gradient difference.[47] Bulk density can affect the biological, chemical, and physical activities processed in the soil system, hence having an influence on soil compaction, structure, and texture. The ideal range for plant growth in clay loam soil types is less than 1.4 g/cm^3, while plants can grow up to 1.48 g/cm^3 within the distressing condition.[48,49]

The soil moisture content is also significantly affected by the terrace position in both depths. The first depth (0-40 cm) of moisture content varies from 22.56% up to 29.32% toward the downslope of the terrace position, and the second layer (40-80 cm) varies from 29.38% up to 39.16% in the same way. This variation may be generated from the soil fertility improvement, such as the deposition zone of the structure is the accumulation zone of basic soil nutrients which resulted in soil fertility improvement. Therefore, it can facilitate storing more water than the loss zone of the structure. It is supported by other similar studies that natural resource conservation activities under the watershed development program had a positive impact on soil fertility and productivity on cultivation land and improved the production potential of crop yield.[50] In addition, the availability of soil water content is greatly influenced by soil OM content, texture, mineralogy, and soil morphology.[35]

In general terrace construction on cultivation, land could make gradient difference, which results in variation in soil physical and chemical properties within the consecutive terrace positions. It also strengthens with other similar studies. In this case, in northern Ethiopia, the effect of soil and water conservation structures was determined, the result of which was it had a positive relationship with most soil chemical and physical properties.[51,52]

Crop yield and biomass production

The predominant crops in the catchment are cereals and pulses which could be growing in 2 cropping seasons: the first season, Belg, the small rain season and the second Kiremt, the main rain season. Belg is the small rain season, used for barely and

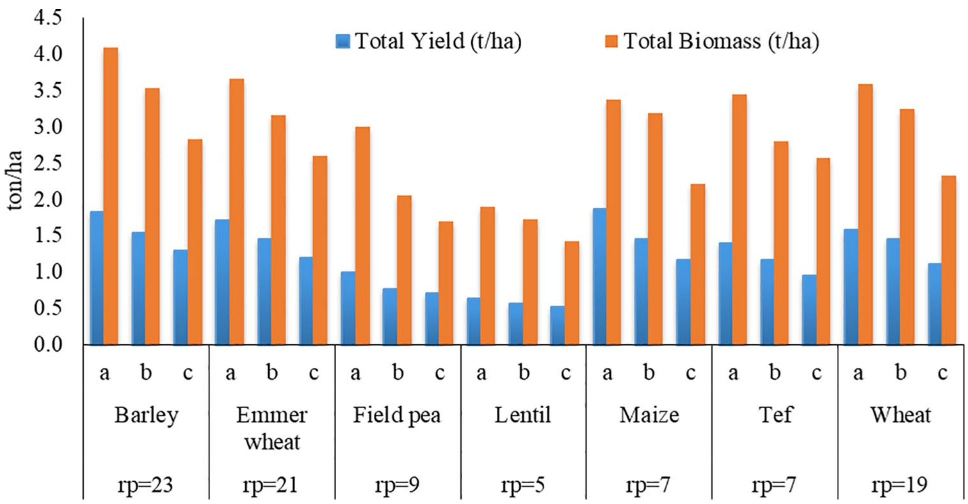

Figure 4. Grain yield and biomass at different positions on terraces (Belg 1991-2018).
a, b and c are the positions of fixed plots: at the upper position of the terrace (a), at the middle position of the terrace (b), and at the lower position of the terrace (c).
rp, number of years each crop was grown from 1989 to 2018.

Table 2. Effect of soil and water conservation structure on some soil physical properties in Maybar subwatershed.

TREATMENT	TEXTURE			TEXTURAL CLASS	BD (G/CM^3)	MC (%)	
	SAND (%)	SILT (%)	CLAY (%)			0-40 CM	40-80 CM
Below slope position	32.50	33.33	34.17	Clay loam	1.48^a	22.56^b	29.38^b
Middle slope position	38.33	30.00	31.67	Clay loam	1.39^a	24.07^{ab}	29.93^b
Upper slope position	31.66	34.17	34.17	Clay loam	1.23^b	29.32^a	39.16^a
Grand mean	34.16	32.50	33.33	Clay loam	1.37	25.32	32.82
CV	5.45	12.30	15.61		4.16	7.93	13.63
Lsd	ns	ns	ns		**	**	*

ns, nonsignificance ($P > .05$). In identical letters, superscripts a, b, and ab have no significance.
*Significant ($P \leqslant .05$).
**Highly significant at ($P \leqslant .01$)

field pea crop production, and during Kiremt, maize, tef, and horse bean are predominant crops.

The most produced varieties are locally adopted, whereas some are introduced by the Ethiopian National Agricultural Research Institute and Sirinka Agricultural Research Center. Before the 2000s, except cow dung and manure, inorganic fertilizers were not adopted by farmers for all crop types, but currently for the same cereal crops DAP and urea are used based on their national recommendation.[53] To reduce the outlier effect of the yield and biomass, results that were collected from the improved variety and supported with inorganic fertilizer had been ignored. In both cropping seasons, the minimum replication that has been considered for the analysis was 5, which is lentil. This means the crops that have been sown less than 5 times over the years were excluded. Each replication indicates the number of mean annual production based on the probability of a fixed plot each crop took.

Crop yield and biomass production. Barely, wheat, emmer wheat, lentil, maize, field pea, and tef were the commonly sown in Belg season. In addition, horse bean pulse crop was produced in the Kiremt season. According to the continuous yield samples of fixed place, all of the results clearly showed that the highest yield immediately above the structure and lowest yield immediately below the structure were recorded (Figure 4). It is also directly related to soil fertility status. The cause of yield reduction in the zone below the structure was due to decreased nutrient level in the soil, caused by loss of topsoil, and moisture stress, caused by reduced effective water storage (Tables 1 and 2).

Results of various studies have indicated that soil and water conservation had improved crop productivity. Physical soil and water conservation structures have the potential to reduce soil loss by decreasing overland flow and mitigating seasonal yield variability by increasing the soil moisture through the retention of rainwater.[54] Terraces are long-term measures requiring higher investments which improve soil moisture-holding capacity and water infiltration and reduces runoff, improves soil water retention and transmission, and reduces drought stress for subsequent crops. One of the ways of addressing soil and water degradation and improving crop productivity is the

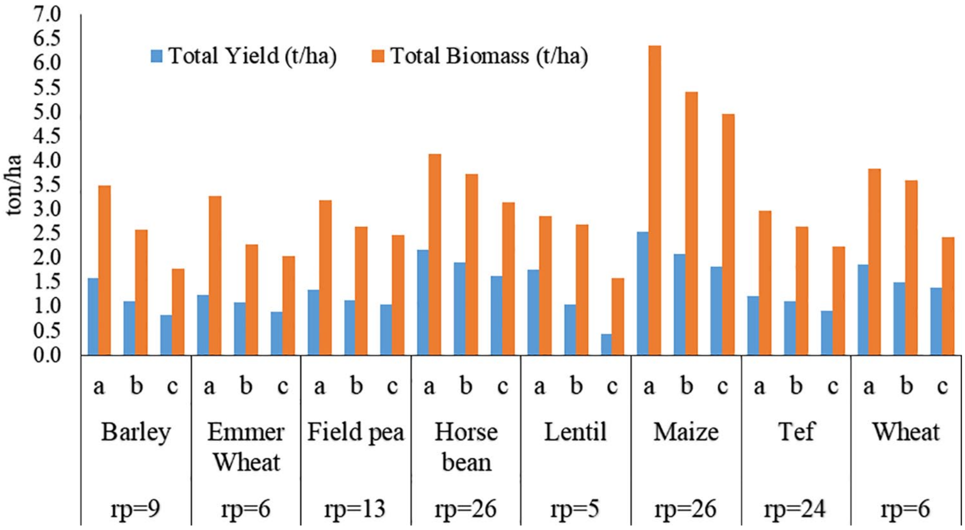

Figure 5. Grain yield and biomass in different positions on terraces (Kiremt 1991-2018).
a, b, and c are the positions of fixed plots: at the upper position of the terrace (a), at the middle position of the terrace (b), and at the lower position of the terrace (c).
rp, the number of years each crop was grown from 1991 to 2018.

use of improved soil and water conservation measures which are the important implications for improving soil fertility.[52]

The change in yield and biomass production between the 2 successive terrace positions was evaluated. The production potential of the gradient difference of the terrace positions varied from lower to the upper parts of the terrace positions. But the change in percentage depended on crop types in Belg cropping season. Barley, emmer wheat, maize, and tef production had declined proportionally, but in the case of wheat crop there is a reduction in production from higher to the middle to the lower part (23.8%) rather than from upper to the middle part of the terrace (8.0%).

In contrast, the redaction percentage of pulse crops (field pea and lentil) is higher when increasing the slope position of the terrace. The production potential of field pea was reduced by 22.4% in the first terrace position (upper to the middle) and was reduced by 8.6% in the second terrace position (middle to lower). Similarly, lentil production also reduced by 11.9% and 6.4% in the first and second terrace positions respectively (Table 3).

The Kiremt season crops that have been commonly produced in the catchment are also analyzed. Similarly, the gradient difference in terrace affects their yield and biomass production. The production potential of the crop was gradually decreased with increasing the gradient difference (Figure 5). It is consistent with selective soil fertility indicators such as soil chemical and physical properties (Tables 1 and 2). The plot that adjusted on immediately above the structure has been relatively higher organic carbon, soil macronutrient, soil moisture content, and appropriate bulk density and pH value.

Similar to the Belg season, the variation in yield and biomass production of the different terrace positions varied from upper to medium and medium to lower parts during the Kiremt season (Table 4).

This result argued with most reports from Ethiopia and many other places. Soil and water conservation project reports that on-farm experimental site results show that the loss of productive area combined with other problems was too great a disadvantage to be balanced by the higher crop yield within the short period of measurement.[13] However, various yield samples taken from fixed places in relation to conservation structures showed that bunds were the most effective measure and there was highest yield immediately above the bunds and lowest yield immediately below the bunds.[47]

The study about soil properties and crop yields along the terraces and topo-sequence of Anjeni Watershed, Central Highlands of Ethiopia, and the deposition zone of the terrace structure were obtained relatively from higher crop yield than elsewhere.[55] The deposition zone in the case of this study is the upper part of the terrace position and the loss zone is the lower part of the terrace position.

Organic matter is one of the cost-effective methods and very important in soil and water conservation for it has a capacity of improving soil chemical and physical properties to affect measured runoff, soil loss, and crop yield.[56] Similarly, in Kenya, the impact of the terraced farm on improvement of maize crop production was studied. The result showed that the lower slope position had the highest maize grain yields compared with the upper slope position.[57]

Annual yields and biomass production of main crops (1989-2018). The annual yield and biomass of predominant cereal crop production potential in both cropping season clearly showed a decreasing trend (Figures 6 to 8). It indicated that removal of topsoil which is the source of most essential plant nutrients did not replenish by only physical soil and water conservation structures. In the study area, mostly the prevalent soil and water conservation measures were physical structures

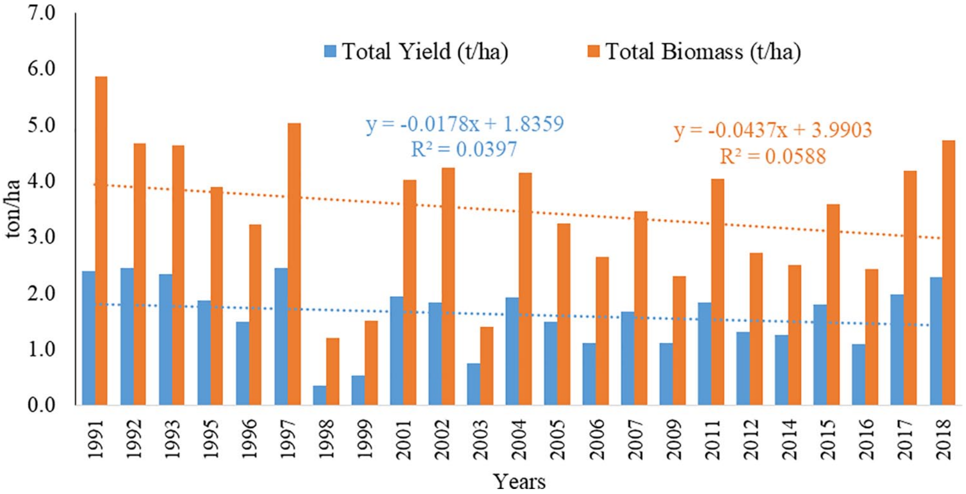

Figure 6. Grain yield and biomass production of Barley in Belg season crops.

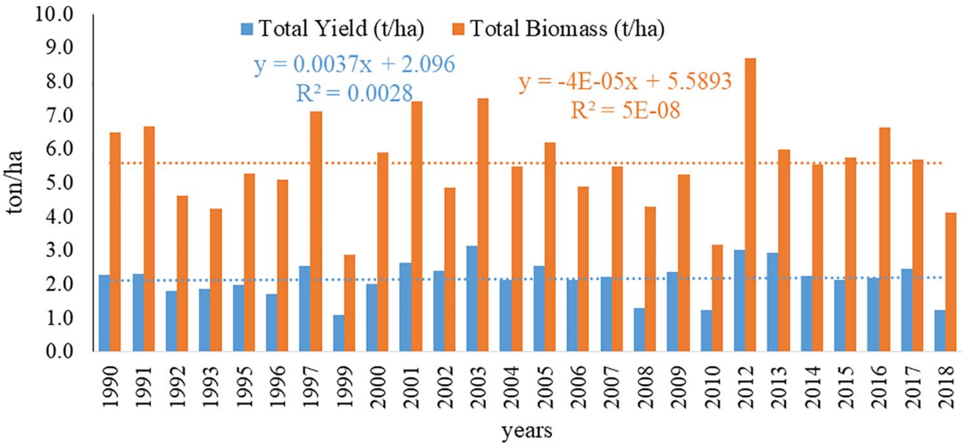

Figure 7. Grain yield and biomass production of maize in Kiremt season.

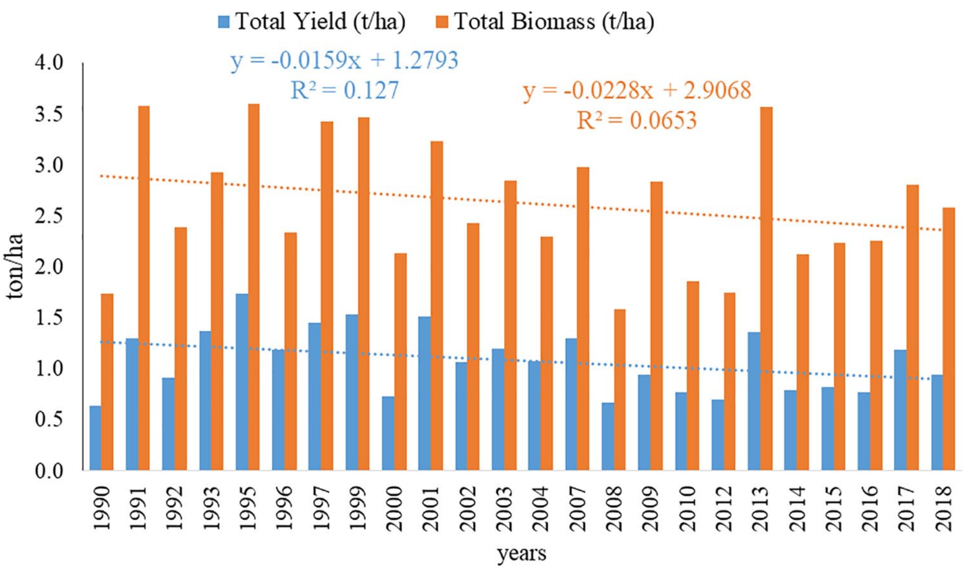

Figure 8. Grain yield and biomass production of tef in Kiremt season.

Table 3. Variation in yield and biomass production at different terrace positions in Belg season.

TYPE OF CROPS	CHANGE IN YIELD (%)		CHANGE IN BIOMASS (%)	
	A-B	B-C	A-B	B-C
Barley	15.45	15.76	13.75	19.80
Emmer wheat	15.13	17.02	13.62	17.82
Field pea	22.35	8.60	31.21	17.69
Lentil	11.94	6.44	8.91	17.45
Maize	20.15	19.54	5.56	30.72
Tef	16.93	17.81	18.93	8.05
Wheat	8.02	23.78	9.57	28.22

a-b, deposition zone to medium terrace position; b-c, medium terrace position to loss zone.

Table 4. Variation in yield and biomass production at different terrace positions in Kiremt season.

TYPE OF CROPS	CHANGE IN YIELD (%)		CHANGE IN BIOMASS (%)	
	A-B	B-C	A-B	B-C
Barley	30.3	25.5	31.2	26.2
Emmer wheat	12.7	18.5	30.7	9.9
Field pea	16.5	6.3	17.3	6.6
horse bean	12.2	14.1	9.7	15.7
Lentil	41.0	57.4	6.3	41.1
Maize	17.9	11.8	14.9	8.3
Tef	8.1	19.0	11.2	15.0
Wheat	7.7	19.5	6.6	32.4

a-b, upper to medium terrace position; b-c, medium to lower terrace position.

rather than integrating biological measures. While it did not strengthen sustainably, earlier some Sesbania species were planted on the physical soil and water conservation structures; there was no integration of any agronomic measures in the cultivation land except crop rotation.[53]

Hence, additional agronomic measures were needed to improve soil fertility, which could be that increased crop productivity was not possible in the study area. Continuous cropping and unbalancing of nutrient replacement and removal of crop or loss through erosion and leaching have been the major causes of decline in soil fertility, which leads to declining crop productivity.[58,59] In contrast, it contradicted CSA Annual Agricultural Sample Surveys of 2001-2017 study that was conducted in the south nation and nationality people of the regional state (SNNPRS) of Ethiopia in Wolaita Zone, in which the average crop production potential increased through time, but the survey had not described or did not consider the agricultural imputes that applied on each crop production systems.[60]

The previous study also indicates that attributes of the soils under the cultivated lands of the study area showed that the most soil fertility indicator which is OM was lower than the adjacent forest and grass land-use types. The most essential nutrients for OM reduction in the cultivation land were nitrogen, phosphorus, and sulfur, which were the base for the most source of plant growth.[38]

Although annual variability has occurred, the annual productivity of pulse crop trends in both cropping season was gradually somewhat increased (Figures 9 and 10). It might be related to the nature of the crops' nutrient requirement. Pulse crops can be produced in low fertile soil rather than cereals. In most pulse crops nitrogen requirement was obtained from the process of nitrogen fixation. Therefore, pulse crops enable up to 90% of their nitrogen requirements from this mechanism.[61]

The amount is determined by indigenous nutrient supply, and moisture availability of the soil nutrient requirement varies considerably depending on the soil fertility and cultivar characteristics. Therefore, the efficiency also depends on the

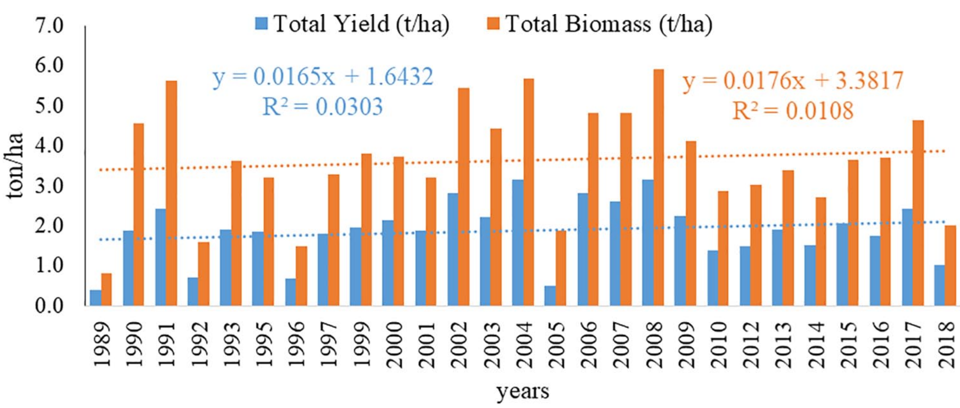

Figure 9. Annual grain yield and biomass production of horse bean in Kiremt season.

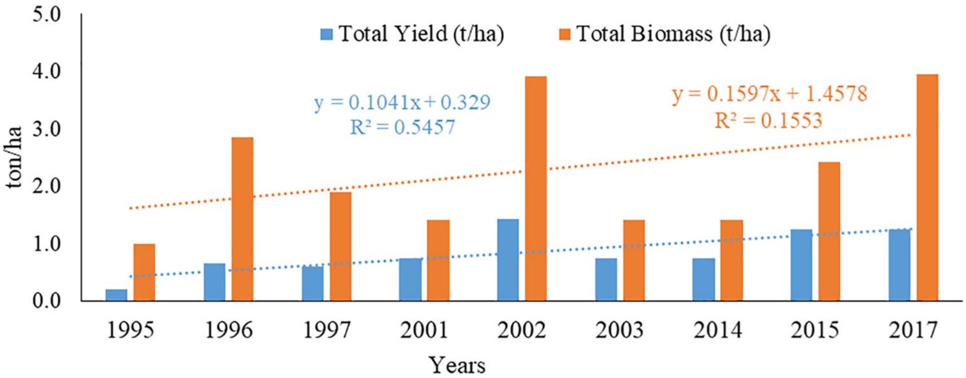

Figure 10. Grain yield and biomass production of field pea in Belg season crops.

formation of nodulation, and the growth of rhizobium is more sensitive to soil acidity than any of the other phases of symbiotic nitrogen fixation.[62]

In general, various studies indicated that farm land terraces could reduce the sediment loss and restrict the power of soil erosion which causes soil fertility. In Debremawi watershed in a West Ethiopian highland, a research was conducted, the result of which shows that terraces could reduce the soil erosion and increase infiltration capacity of the soil.[63,64] Soil and water conservation structures in a long time create the land terrace, which results in reducing soil erosion by reducing the speed of runoff. The process is also used in deposition of soils on the terraced land, which results in increasing soil moisture content and enhancing soil fertility status of the land.[65] Therefore, the terrace-based soil and water conservation structures contribute a significant role for agricultural production and productivity.[66] In contrast, due to computing, the cultivable land physical soil and water conservation structures have low effect on crop production rather than agronomic measures for enhancing crop productivity increment.[64]

Summary and Conclusion

The study reveals that crop yield and biomass production within the soil and water conservation structure, immediately above the structure, are higher than that below the structure. But the annual production potential over the last 2 decades did not show significant change; rather, the production potential of cereal crops was slightly reduced, but pulse crops slightly increased. This indicates that interventions have not brought productivity improvement in crop production or could not compensate for the annual basic nutrient loss. Soil fertility status of the cultivation land has been affected by the soil and water conservation structures. Therefore the terrace building had made the soil gradient different, which has higher soil fertility status indicated at the deposition zone or at the upper position of the terrace. While some properties did not show a significant difference, most of the soil chemical and physical properties show higher differential improvement in the deposition part than elsewhere.

In general, long-term watershed management in Maybar subcatchment indicated that soil and water conservation structures made a gradient difference, the results of which would be soil fertility and crop productivity variation within the terrace positions. Therefore, even though soil and water conservation measures in Maybar subwatershed changed to a terraced level, the production potential did not significantly improve. To improve such a problem, farmers have to be advised to apply agronomic measures for soil fertility improvement complementing physical soil and water conservation practice.

Acknowledgements

I would like to thank my respected colleagues from soil and water management research directorate, Sirinka Agricultural Research Center.

Author Contributions

TT: involved in the data collection, analysis, review, and discussion of the findings. Aw M: involved in the data collection, review, and discussion of the findings. Al M: involved in the data collection, review, and discussion of the findings. ML: assisting with data collection and encoding. WA: assisting with data collection and encoding.

ORCID iDs

Muluken Lebay https://orcid.org/0000-0001-5733-2506
Wudu Abiye https://orcid.org/0000-0003-0083-0090

REFERENCES

1. Asmamaw DK. A critical review of integrated river basin management in the upper Blue Nile river basin: the case of Ethiopia. *Int J River Basin Manag*. 2015;13:429-442. doi:10.1080/15715124.2015.1013037.
2. Chimdesa G. Historical perspectives and present scenarios of watershed management in Ethiopia. *Int J Nat Resour Ecol Manag*. 2016;1:115-127.
3. Watson SD, Watson SD. Disaster risk reduction. *Int Order Polit Disaster*. 2019:93-123. doi:10.4324/9780429259272-5.
4. Legesse A, Bogale M, Likisa D. Impacts of community based watershed management on land use/cover change at elemo micro-watershed, Southern Ethiopia. *Am J Environ Prot*. 2018;6:59-67.
5. Scherr SJ. A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. *Food Policy*. 2000;25:479-498. doi:10.1016/S0306-9192(00)00022-1.
6. Gebregziabher G, Abera DA, Gebresamuel G, Giordano M, Langan S. An assessment of integrated watershed management in Ethiopia. http://pure.iiasa.ac.at/id/eprint/14393/1/wor170.pdf. International Water Management Institute (IWMI) Working Paper 170. Published 2016.
7. Osman M, Sauerborn P. Soil and water conservation in Ethiopia experiences and lessons. *Soils Sediments*. 2001;1:117-123.
8. Hurni H. Degradation and conservation of the resources in the Ethiopian highlands. *Mt Res Dev*. 1988;8:123-130.
9. Kidane D. Conservation tillage implementation under rain fed agriculture: implication for soil fertility, green water management, soil loss and grain yield in the Ethiopian highlands. *Int J Agric Sci*. 2014;4:268-280.
10. Habtamu T. Assessment of sustainable watershed management approach case study Lenche Dima, Tsegur Eyesus and Dijjil watershed. Paper presented at: The Faculty of the Graduate School of Cornell University; May 2011; Ithaca, NY.
11. Dejene A. Integrated natural resources management to enhance food security—the case for community-based approaches in Ethiopia. http://www.fao.org/3/Y4818E/y4818e00.htm. Environment and Natural Resources Working Paper No. 16. Published 2003.
12. Desta L, Carucci V, Wendem-Agenehu A, Abebe Y. *Community Based Participatory Watershed Development: A Guideline*. Addis Ababa, Ethiopia: Ministry of Agriculture and Rural Development; 2005.
13. Soil Conservation Research Project. *Area of Maybar, Wello, Ethiopia: Long-Term Monitoring of the Agricultural Environment 1981 – 1994*. Bern, Switzerland: University of Berne; 2000.
14. Sahrawat KL, Wani SP, Pathak P, Rego TJ. Managing natural resources of watersheds in the semi-arid tropics for improved soil and water quality: a review. *Agric Water Manag*. 2010;97:375-381. doi:10.1016/j.agwat.2009.10.012.
15. Gashaw T. The implications of watershed management for reversing land degradation in Ethiopia. *Res J Agric Environ Manag*. 2015;4:5-12.
16. Alemayehu F, Tahaa N, Nyssenc J, et al. The impacts of watershed management on land use and land cover dynamics in eastern Tigray (Ethiopia). *Resour Conserv*. 2009;53:192-198.
17. Sisay D. *Rainfall-Runoff Processes at a Hillslope Watershed: Case of Simple Models Evaluation at Kori Sheleko Catchment of Wolo, Ethiopia* [MSc thesis]. Wageningen, The Netherlands: Wageningen University; 2005.
18. Tesfaye G, Assefa A, Kidane D. Runoff, sediment load and land use/cover change relationship: the case of Maybar sub-watershed, South Wollo, Ethiopia. *Int J River Basin Manag*. 2017;15:89-101. doi:10.1080/15715124.2016.1239625.
19. Bosshart U. Measurement of river discharge for the SCRP research catchments: gauging station profiles. Soil Conservation Research Project, Research No. 30. *Published* 1997.
20. Mitiku H, Herweg K, Stillhardt B. *Sustainable Land Management: A New Approach to Soil and Water Conservation in Ethiopia*. Bern, Switzerland: Centre for Development and Environment; 2006.
21. Hurni H, Tato KZ, Eleke G. The implications of changes in population, land use, and land management for surface runoff in the upper Nile basin area of Ethiopia. *Mt Res Dev*. 2005;25:147-154.
22. SCRP. *Soil and Water Conservation Project, Second Progress Report*. Bern, Switzerland: University of Bern, Switzerland in Association with MOA, Ethiopia; 1982.
23. Gregory PJ. Growth and functioning of plant roots. In: Wild A, ed. *Russell's Soil Conditions and Plant Growth*. London, England: Longman; 1988:113-167.
24. Wilding LG. Soil spatial variability: its documentation, accommodation and implication to soil surveys. In: Nielsen DR, Bouma J, eds. *Soil Spatial Variability*. Wageningen, The Netherlands: Pudoc; 1985:166-187.
25. Funakawa S, Yoshida H, Watanabe T, Sugihara S, Kilasara M, Kosaki T. Soil fertility status and its determining factors in Tanzania. In: Hernandez Soriano MC, ed. *Soil Health and Land Use Management*. Rijeka, Croatia: IntechOpen; 2012:3-16. doi:10.5772/29199.
26. Blake GR. Bulk density. In: Black CA, ed. *Methods of Soil*. Madison, IL: American Society of Agronomy; 1965:374-399.
27. Bouyoucos G. Hydrometer method improved for making particle size analyses of soils. *Agron J*. 1962;54:464-465.
28. Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci*. 1934;37:29-38.
29. Van Reeuwijk L. Procedures for soil analysis. *Int Soil Ref Inf Cent*. 1992:9:106.
30. Bremner JM, Mulvaney CS. Nitrogen–total. In: Page AL, ed. *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties*. Madison, IL: American Society of Agronomy; 1983:595-624.
31. Olsen SR, Sommers LE. *Methods of Soil Analysis. Part 2* (ed. Page AL). Madison, IL: American Society of Agronomy; 1982:403-430.
32. Mamo T, Haque I. Phosphorus status of some Ethiopian soils, II. Forms and distribution of inorganic phosphates and their relation to available phosphorus. *Trop Agri*. 1991;68:2-8.
33. Nadler A, Frenkel H. Determination of soil solution electrical conductivity from bulk soil electrical conductivity measurements by the four-electrode method 1. *Soil Sci Soc Am J*. 1980;44:1216-1221.
34. University of Berne, Institute of Geography. *Data Preparation, Analysis and Interpretation of Data compiled at the Research Stations July 2004, Version 1*. Bern, Switzerland: University of Berne; 2004:1-58.
35. Landon JR, ed. *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*. New York, NY: Routledge; 1991.
36. Bai Z, Li H, Yang X. The critical soil P levels for crop yield, soil fertility and environmental safety in different soil types. *Plant Soil* 2013;372:27-37. doi:10.1007/s11104-013-1696-y.
37. DeLonge MS, Miles A, Carlisle L. Investing in the transition to sustainable agriculture. *Environ Sci Policy*. 2016;55:266-273. doi:10.1016/j.envsci.2015.09.013.
38. Gebeyaw T. Assessment of soil fertility variation in different land uses and management practices in Maybar Watershed. *Int J Environ Bioremedi Biodegrad*. 2015;3:15-22. doi:10.12691/ijebb-3-1-3.
39. Butros IH, Taimeh AY, Feras MZ. Variation in soil chemical properties along toposequences in an Arid Region of the Levant. *Catena*. 2010;83:34-45.
40. Beshir S, Lemeneh M, Kissi E. Soil fertility status and productivity trends along a toposequence: a case of Gilgel Gibe catchment in Nadda Assendabo watershed, Southwest Ethiopia. *Int J Environ Prot Policy*. 2015;3:137-144. doi:10.11648/j.ijepp.20150305.14.
41. Awdenegest M, Nicholas H. Soil fertility in relation to slope position and agricultural land use: a case study of Umbulo catchment in Southern Ethiopia. *Environ Manage*. 2008;42:753-763. doi:10.1007/s00267-008-9157-8.
42. Adimassu Z, Mekonnen K, Yirga C, Kessler A. Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. *Land Degrad Dev*. 2014;25:554-564.
43. Emiru N. *Land Use Changes and Their Effects on Soil Physical and Chemical Properties in Senbat Sub-Watershed, Western Ethiopia* [doctoral dissertation]. Alemaya, Ethiopia: Alemaya University; 2006.
44. Dercon G, Deckers J, Govers G, et al. Spatial variability in soil properties on slow-forming terraces in the Andes region of Ecuador. *Soil Till Res*. 2003;72:31-41. doi:10.1016/S0167-1987(03)00049-7.
45. Selassie YG, Anemut F, Addisu S. The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. *Environ Syst Res*. 2015;4:1-7. doi:10.1186/s40068-015-0027-0.
46. Demelash M, Stahr K. Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia. *J Soil Sci Environ Manag*. 2010;1:164-176.

47. Shiene SD. Effectiveness of soil and water conservation measures for land restoration in the Wello area, northern Ethiopian highlands. https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/5136. Published November 2012.
48. White RE. *Principles and Practice of Soil Science: The Soil as a Natural Resource*. New York, NY: John Wiley & Sons; 2013.
49. Nyssen J, Poesen J, Gebremichael D, et al. Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia. *Soil Till Res*. 2007;94:151-163. doi:10.1016/j.still.2006.07.011.
50. Wakene N. *Assessment of Important Physicochemical Properties of Dystric Udalf (Dystric Nitosols) Under Different Management Systems in Bako Area, Western Ethiopia* [MSc thesis]. Alemaya, Ethiopia: Alemaya University; 2001.
51. Hishe S, Lyimo J, Bewket W. Soil and water conservation effects on soil properties in the Middle Silluh Valley, northern Ethiopia. *Int Soil Water Conserv Res*. 2017;5:231-240. doi:10.1016/j.iswcr.2017.06.005.
52. Belayneh M, Yirgu T, Tsegaye D. Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile Basin, Ethiopia. *Ecolog Process*. 2019;8:36.
53. Albko Woreda Agricultural office (AWAO). *Anu reports* (Unpublished). History of Defatit Maybar Developmental Watershed, 2000.
54. Bekele W, Drake L. Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia: a case study of the Hunde-Lafto area. *Ecol Econ*. 2003;46:437-451. doi:10.1016/S0921-8009(03)00166-6.
55. Amare T, Terefe A, Selassie YG, Yitaferu B, Wolfgramm B, Hurni H. Soil properties and crop yields along the terraces and toposequece of Anjeni soil properties and crop yields along the terraces and toposequece of Anjeni Watershed, Central Highlands of Ethiopia. *J Agric Sci*. 2013;5:134-144. doi:10.5539/jas.v5n2p134.
56. Mohammed S. *The Effect of Organic Matter on Runoff, Soil Loss and Crop Yield*. Sunnyvale, CA: Lambert Academic Publishing; 2003.
57. Ruto AC. *Optimizing Moisture and Nutrient Variability Under Different Cropping Patterns in Terraced Farms for Improved Crop Performance in Narok County, Kenya* [doctoral dissertation]. Nairobi, Kenya: University of Nairobi; 2015.
58. van Beek CL, Elias E, Yihenew GS, et al. Soil nutrient balances under diverse agro-ecological settings in Ethiopia. *Nutr Cycl Agroecosyst*. 2016;106:257-274.
59. Hailu H, Mamo T, Keskinen R, Karltun E, Gebrekidan H, Bekele T. Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. *Agric Food Secur*. 2015;4:1-10.
60. Cochrane L, Bekele YW. Data in brief average crop yield (2001–2017) in Ethiopia: trends at national, regional and zonal levels. *Data Br*. 2018;16:1025-1033. doi:10.1016/j.dib.2017.12.039.
61. Thiyagarajan TM, Backiyavathy MR, Savithri P. Nutrient management for pulses—a review. *Agric Rev*. 2003;24:40-48.
62. Robson AD. Nutrient requirements of pulses. In: Summerfield RJ, ed. *World Crops: Cool Season Food Legumes*. Dordrecht, The Netherlands: Springer; 1988:869-881.
63. Dagnew DC, Guzman CD, Zegeye AD, et al. Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: the Debre Mawi watershed. *J Hydrol Hydromech*. 2015;63:210-219. doi:10.1515/johh-2015-0021.
64. Adimassu Z, Langan S, Johnston R, Mekuria W, Amede T. Impacts of soil and water conservation practices on crop yield, run-off, soil loss and nutrient loss in Ethiopia: review and synthesis. *Environ Manage*. 2017;59:87-101. doi:10.1007/s00267-016-0776-1.
65. Belay A, Eyasu E. Effect of soil and water conservation (SWC) measures on soil nutrient and moisture status, a case of two selected watersheds. *J Agric Ext Rural Dev*. 2019;11:85-93. doi:10.5897/jaerd2017.0862.
66. Kassie M, Pender J, Yesuf M, Kohlin G, Bluffstone R, Mulugeta E. Impact of soil conservation on crop production in the Northern Ethiopian Highlands. http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/125280/filename/125281.pdf. IFPRI Discussion Paper 00733. Published December 2007.