Impacts of soil and water conservation measures and slope position on selected soil attributes at a watershed scale

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Abstract

Background: The Ethiopian highlands are affected by soil loss caused by soil erosion resulted in soil properties deterioration. To reverse this, different soil and water conservation (SWC) measures were spatially practiced; however, the effect of SWC and slope gradient on soil properties is not studied well in the area. Hence, this study was conducted to evaluate the effects of SWC and slope gradient on selected soil physicochemical properties at Dawnt watershed, North-western Ethiopia. The treatments were a combination of four different SWC measures with three slope gradients replicated at three sites. Disturbed and undisturbed soil samples were collected from 0-20cm soil depth and physicochemical properties were determined following standard laboratory procedures.

Results: The lab results depict that sand, bulk density, moisture, particle density, porosity, pH, organic carbon (OC), cation exchange capacity (CEC), total nitrogen, and available phosphorus were significantly ($P<0.05$) affected by SWC measures and slope gradient. High OC (2.44%), CEC (45cmol (+) kg^{-1}), and moisture (19.55%) were obtained from Stone-Faced Soil Bund stabilized with Grass (SFSBG) and high available phosphorus (7.83ppm) from Soil Bund (SB) while lower bulk density (1.13gm/cm^3) from SFSBG. Additionally, higher clay (41.67%) and moisture (19.81%) and lower bulk density (1.14g/cm^3) were obtained from the lower slope. Higher pH (6.75) and OC (2.89%) were recorded at lower slope under SFSBG and lower pH and OC (6.03 and 1.02%) at the upper slope with non-conserved. Soil chemical properties, except available potassium, were increased down the slope.

Conclusion: The interactions of slope position and SWC measures affect soil texture; pH, organic carbon, and available phosphorus but do not affect soil bulk density, moisture content, particle density, total porosity, cation exchange capacity, total nitrogen, and available potassium. In generally, the soil properties were improved through integrating conservation practices with multipurpose grass species across the study watershed. Therefore, in the study watershed and other similar agro-ecologies, farmers should use integrated SWC measures to avert the rainfall-driven soil nutrient loss.

Introduction

Humans get more than 99.7% of their food from the land and less than 0.3% from the ocean and aquatic ecosystem (Lal 2004). Thus, preserving cropland and maintaining soil fertility and productivity should be of the highest significance to human prosperity (Kagambèga *et al.* 2017). About 10 million hectares of croplands are lost each year due to soil erosion which leads to a reduction in crop yield and food production worldwide (Pimentel and Burgess 2013). According to (Lal 2004), two-thirds of the world's population is malnourished as a result of cropland reduction. Similarly, (Pimentel and Burgess 2013) reported that soil was being lost 10 to 40 times faster from the agricultural lands than the rate of soil formation. The major causes of land degradation in Ethiopia are rapid population increase, deforestation, low vegetative cover, and unbalanced crop and livestock production (Taddese 2001). Generally, natural resource degradation is the main environmental problem in Ethiopia (Addis *et al.* 2020).

The majority of farmers in Ethiopia are subsistence-oriented, cultivating sloppy lands that are susceptible to soil erosion (Taye *et al.* 2013). Crop production is inhibited not only by low input utilization and technology level but also by land fragmentation and soil erosion (Kassa *et al.* 2013). The pressure of intense human activity and improper farming and management practices pose serious threats to the sustainability and suitability of the soil for crop production (Liu *et al.* 2020). Ethiopia is considered as one of the least developed countries where agriculture had always played a central role in the country's economy. The Ethiopian highlands have been experiencing declining soil fertility and severe soil erosion due to intensive farming on steep and fragile lands (Tadesse and Belay 2004). Bobe (2005) reported that, soil loss in the Ethiopian highlands was estimated to reach up to 300 t $ha^{-1}yr^{-1}$ with an average of about 70 t $ha^{-1}yr^{-1}$.

Soil erosion in the Northwestern Amhara Region, Ethiopia has been a subject of anxiety, resulting in a major environmental threat to the sustainability of agricultural land (Addis *et al.* 2016b). Gondar highland is one of the most soil erosion vulnerable parts of Ethiopia, as the area has a high erosive force of rainfall, intense land uses, and high population pressure (Addis *et al.* 2015). Hence, this study attempts to understand the effects of different SWC and slope classes on soil physicochemical properties of the soil.

The world population is growing in an alarming rate as a result needs for natural resource become high, which enhance deforestation, overgrazing, continuous cultivation and ultimately change the natural ecosystem. In Ethiopia, erosion by water is the most serious land degradation problem (Tamene and Vlek 2008). Plants need a favorable soil environment; however, due to the removal of soil by erosion soil cannot create a favorable environment and supply sufficient nutrient range for the optimal growth and development of plants. In the study watershed, almost all soil management activities were done similarly along the slope, although, the specific area needs particular soil management practices.

The Ethiopian government responded with large-scale rehabilitation measures and the establishment of various soil and water conservation (SWC) interventions across the country to counteract the ongoing soil depletion (Herweg and Ludi 1999; Addis *et al.* 2016b). Similarly, the local administration of the study area introduced and implemented different SWC measures through mass mobilizations of the local community and the elderly were the most responsible person that actively participated in implementing SWC structures and tried to rehabilitate the area from soil degradation. However, in the watershed, the significant contributions of SWC measures in improving the soil properties since the introduction period were not known. Meanwhile, scientifically quantifying the impacts of SWC measures and slope gradient on the soil properties status and availing the findings for the community and policymakers is timely and crucial and helps for the decision-makers whether the present practices are fruitful or need further modification. Therefore, this research aimed to evaluate the effects of SWC measures and slope gradient on selected soil physicochemical properties at Dawnt Watershed, North Western Ethiopia.

Materials And Methods

Description of the study area

The study was conducted on farmers' cropland in Dawnt Watershed, Shor-Sar-Wuha kebele, Gondar Zuria District. The District is located in the Central Gondar Administrative Zone of the Amhara National Regional State. The watershed is geographically located within 12º17'184" to 12º18'733"N and 37º 36' 486" to 37º36'359"E. The watershed covers a total area of 444.3 ha with a total population of 9,045. The annual mean minimum and maximum temperatures of the watershed were 21^{0}C and 28^{0}C, respectively. The annual rainfall of the study area ranges from 950 to 1,035 mm, while the altitude ranges from 1962 to 2185 meters above sea level. In general, the watershed has 5% cool and 95% cool semi-humid agroecology while the topographic conditions of the area composed of 0.34% of the watershed flat to gentle (0–3%), 5.26% of the watershed moderate (3–12%), 8.17% of the watershed steep (12–20%), 27.91% of the watershed very steep (20–35%) and 58.32% of the watershed extreme (> 35%). The three major soil color, widely distributed in the watershed includes 5% red (Nitisols), 85% brown (Cambisols) and 10% black (Vertisols) with the soil depth of the watershed ranges from 20 to 100 cm.

Land use pattern and major agricultural activities

Although the land-use patterns of the 444.3ha watershed are highly dynamic about 146.7ha cultivated, 60.02ha grazing, 56.49ha plantation forest, and 130.41ha reforested by trees and shrubs, 36.16ha settlement, and 14.52ha bare land. While the watershed is characterized by subsistence mixed farming of rainfed agriculture and livestock.

Experimental design and sampling techniques

The study consisted of a factorial combination of four levels of SWC (non-Conserved (C), Stone-Faced Soil Bund (SFSB), Stone-Faced Soil Bund stabilized with Kidan Grass (SFSBG) and Soil Bund (SB)) and three slope gradient class levels [Upper slope (30–60%)), middle slope (15–30%)) and lower slope (10–15%)] with a total of 12 treatments replicated three times resulting in 36 composite soil samples. Three sub-plots (3m by 3m) separated by 5 m intervals within each treatment were established. Meanwhile, soil samples from the four corners and at the center of each sub-plot were collected and thoroughly mixed to make a composite sample and about 2 kg from each sub-plot were collected from the surface soil horizon (0–20 cm) for chemical and physical analyses. Soil samples from four levels of SWC under three slope steepness classes: (30–60%), (15–30%), and (10–15%) were collected using a bucket auger and the undisturbed soil samples were collected from each plot using core cylinder equipment.

Sample preparation and laboratory analysis

The cleaned and air-dried soil samples were ground, then passed through a 2 mm sieve for the determination of the soil parameters, while soil total nitrogen and organic carbon were determined from samples sieved with 0.5 mm. The soil texture was analyzed by the Bouyoucous hydrometer method (Jensen *et al.* 2017). Soil bulk density (BD) was determined from oven dried undisturbed cores as mass per volume of oven dried soil (Osunbitan *et al.* 2005). Soil moisture was determined by the gravimetric method (Shukla *et al.* 2014). Soil particle density (PD) is the ratio of the mass (oven-dry weight) of the soil particles to the particle volume (only solid no pore space) and calculated through the following equation.

$$\text{Soil PD (gm/cm}^3\text{)} = \frac{Mass\ of\ oven\ dyr\ soil\ (Ms)}{Volume\ of\ soil\ particles\ (Vs) or\ solids} \times 100 \text{ (Flint and Flint 2002).}$$

Total porosity (TP) is a measure of the void spaces in soil, represented as the volume of voids divided by the total volume of soil and TP (%) of a soil occupied by pore space was calculated as follows:

$$\text{Total porosity (\%)} = \left(1 - \frac{BD}{PD}\right) \times 100 \text{ (Keller and Håkansson 2010).}$$

The soil pH was determined by the potentiometric method at a 1:2.5 soil to water ratio (Hailu *et al.* 2012). Soil organic carbon was analyzed by using the Walkley and Black titration method (Gelman *et al.* 2012). Soil CEC was determined by ammonium acetate saturation method at pH 7.0 (Buurman *et al.* 1996). The soil total nitrogen was determined by the Kjeldahl method (Dieckow *et al.* 2007). Soil available phosphorus was determined by the Olson method (Iatrou *et al.* 2014). Available potassium was determined using the ammonium acetate solution method and measured by flame Photometer (Affinnih *et al.* 2014).

Statistical analysis

The data were subjected to statistical analysis with Analysis of Variance (ANOVA) in Statistical Analysis Software (SAS). Statistically significant different means were separated using the Least Significant Difference (LSD) test techniques at a 5% significance level.

Results And Discussion

Effects of SWC on selected soil attributes

Soil texture

Two different soil textural classes were determined within the Dawnt Watershed: clay loam, and clay. The resulting soil clay and silt contents were not significantly ($P > 0.05$) affected by soil and water conservation measures (Table 1). However, relatively higher clay content was obtained from the land treated by soil bund followed by the control (Table 1). Whereas, relatively higher silt content was obtained from stone-faced soil bund stabilized with kidan grass followed by stone-faced soil bund (Table 1). Similarly, Mohawesh *et al.* (2015) described that the variation of clay and silt contents as a result of bunds seemed to be insignificant, however, it takes a very long time to stabilize clay and silt contents after the construction of bunds.

Sand content was significantly ($P < 0.01$) affected by soil and water conservation measures and the higher sand contents (30.0% and 28.89%) were recorded at stone-faced soil bund and non-conserved, respectively. While, the lowest sand content (24.22%) was measured on stone-faced soil bund stabilized with kidan grass. Numerically, the higher silt and significantly the lower sand contents were observed from the stone-faced soil bund stabilized with kidan grass and this might be due to the fact that kidan grass has conserved the soil particles from erosion by reducing runoff and improving the soil organic matter through decomposition (Table 1). Mekonen and Tesfahunegn (2011) and Tesfahunegn *et al.* (2011) also stated, sand content had been significantly affected by SWC measures.

Table 1
Effects of SWC measures on selected soil physicochemical properties in the study watershed

Conservation measures	Parameters												
	Clay (%)	Silt (%)	Sand (%)	BD (gm/cm^3)	MC (%)	PD (gm/cm^3)	TP (%)	pH (H_2O)	OC (%)	CEC(cmol(+)kg^{-1})	TN (%)	Ava.P (ppm)	Ava.K (cmol(+)kg^{-1})
C	38.44	32.67	28.89a	1.48a	11.01a	1.89a	20.89a	6.20c	1.36c	37.01c	0.13b	3.03c	0.42b
SFSB	35.56	34.44	30.00a	1.24b	14.48b	2.30b	44.66b	6.42ab	2.06b	43.67b	0.16a	4.76b	0.42b
SFSBG	38.22	37.56	24.22b	1.13c	19.55c	2.43b	51.93c	6.46a	2.44a	45.00a	0.17a	5.75b	0.60a
SB	40.89	33.56	25.56b	1.16c	17.70c	2.35b	46.49b	6.37b	2.42a	43.87b	0.17a	7.83a	0.56a
LSD (0.05)	Ns	Ns	2.87	0.04	2.62	0.15	4.59	0.06	0.30	1.09	0.02	1.20	0.10
CV (%)	9.95	10.75	10.82	12.97	17.10	16.71	11.46	8.60	14.61	12.64	12.00	22.92	19.59

BD = Bulk density, MC = Moisture content, PD = Particle density, TP = Total porosity, CEC = Cation exchange capacity, Total nitrogen, Ava.P = Available Phosphors, Ava.K = Available Potassium, OC = Organic carbon, C = Non-conserved, SFSB = Stone faced soil bund, SFSBG = Stone faced soil bund stabilized with kidan grass, SB = Soil bund, LSD = List significant difference, CV = Coefficient of variation

Bulk density, moisture content, particle density, and total porosity

Soil and water conservation measures significantly ($P < 0.01$) affected soil bulk density, moisture content, particle density, and total porosity (Table 1). The highest bulk density (1.48gm/cm^3) was obtained from non-conserved land followed by stone-faced soil bund (1.24 gm/cm^3). Meanwhile, the lowest (1.13gm/cm^3) was obtained from stone-faced soil bund stabilized with kidan grass. The highest moisture content (19.55%) at stone-faced soil bund stabilized with kidan grass and the lowest (11.01%) at non-conserved land. Similarly, the highest particle density (2.43 gm/cm^3) at stone-faced soil bund stabilized with kidan grass and the lowest (1.89 gm/cm^3) at non-conserved land. The highest total porosity (51.93%) at stone-faced soil bund stabilized with kidan grass and the lowest (20.89%) at non-conserved land was recorded (Table 1).

The result is in agreement with (Muhammad *et al.* 2016) who reported that SWC practices can intercept rainwater and enhance the soil moisture contents. Similarly, Husen *et al.* (2017) and Sinore *et al.* (2018) argued the improvement of soil bulk and particle density with Vetiver grass conservation measures. This might be due to the reduction of physical soil loss by the conservation measures and reduction of slope length and steepness. Besides, different scholars (Gesesse *et al.* 2013; Challa *et al.* 2016; Gadisa and Hailu 2020) also reported significantly lower bulk density and higher total porosity from the conserved land probably because conservation measures reduced runoff speed and enhanced infiltration.

Moreover, soil bulk density and moisture content were significantly different between stone-faced soil bund stabilized with kidan grass with stone-faced soil bund conservation structure and non-conserved land. Soil particle density of non-conserved land had been significantly different from other conservation measures. Total porosity was showed a significant difference between stone-faced soil bund stabilized with kidan grass and other conservation measures. Similarly, Tadesse *et al.* (2016) stated that integrating bunds with forage species was a better option to improve soil properties than bunds alone.

Soil pH, organic carbon, and cation exchange capacity

The analysis of variance showed soil pH, organic carbon, and cation exchange capacity were significantly ($P < 0.01$) affected by SWC measures (Table 1). The highest soil pH (6.46), organic carbon (2.44%), and cation exchange capacity (45.00 cmol (+) kg^{-1}) were obtained from a stone-faced soil bund stabilized with kidan grass; while the lowest pH (6.20), organic carbon (1.36%) and cation exchange capacity (37.01cmol (+) kg^{-1}) were obtained from the non-conserved land.

As a matter of fact, soil pH is influenced by leaching of the exchangeable base, acid rain, decomposition of organic matter, application of commercial fertilizer, SWC measures, and other farming practices (Tanto and Laekemariam 2019). Most of these factors could probably be similar in the watershed, thus, the resulting significant variation in pH might be due to the effect of SWC measures. Besides, (Sinore *et al.* 2018) reported that soil pH, organic carbon, and cation exchange capacity were significantly improved with the use of SWC practices supported by elephant grass and Sesbania. They also stated that the presence of high pH under elephant grass and Sesbania was attributed to the presence of high organic matter, clay fraction, and better cation exchange capacity in the conserved land.

Significantly higher organic carbon and CEC were obtained from SFSBG while the lowest from the non-conserved plot (Table 1). The higher organic carbon content from the SFSBG might be attributed to the organic matter content retained from the organic residues washed down from the upper slope; and additions from kidan grass. This confirmed supporting the physical conservation with biological measures can improve the soil properties. In line with this result, (Hishe *et al.* 2017) reported significant difference in organic carbon content among the conserved and non-conserved landscapes. Similarly, the highest CEC for the same plot might be attributed to the deposition of clay particles washed down from the upper slope position in the conservation measures.

Total nitrogen, available phosphorus, and available potassium

The analysis of variance reflected soil total nitrogen, available phosphorus, and available potassium showed highly significant ($P < 0.01$) variation as a result of SWC measures. The highest soil total nitrogen (0.17%) was recorded at stone-faced soil bund stabilized with kidan grass and soil bund and the highest available phosphorus (7.83ppm) was recorded at soil bund, while the highest available potassium (0.60cmol (+) kg^{-1}) was recorded at stone-faced soil bund stabilized with kidan grass. The lowest total nitrogen (0.13%) and available phosphorus (3.03ppm) were recorded at non-conserved land; while the lowest available potassium (0.42cmol (+) kg^{-1}) was observed at non-conserved and stone-faced soil bund (Table 1).

In line with this study, (Sinore *et al.* 2018) reported higher soil total nitrogen and available phosphorus significantly improved under Sesbania due to high biomass return from Sesbania, a contribution from symbiotic nitrogen fixation and reduction of soil and organic fraction for nitrogen and available phosphorus due to change in pH, and limited soil loss via erosion. (Alemayehu and Fisseha 2018) also pointed out that, total nitrogen and available phosphorus reflected a significant difference and this difference among conserved and non-conserved treatments could be due to the bio-physical conservation measures. Moreover, (Rashid *et al.* 2016; Teressa 2017) confirmed that total nitrogen, available phosphorus, and available potassium were significantly varied due to conservation measures. This might be attributed to the availability of higher soil moisture and reduction of rainfall-driven erosion, and implementation of stone bund could maintain soil fertility.

Effects of slope gradient on selected soil properties

Soil texture

The analysis of variance revealed soil clay and sand particles showed significant ($P < 0.01$) change due to slope gradient. Mean separation also showed that clay content at lower slope classes had significantly different from upper and middle slope classes (Table 2). While, sand particle at all slope classes showed a significant variation (Table 2). The result also showed that the highest clay (41.67%) and sand (30.00%) contents were recorded at lower and upper slope classes respectively. Different scholars (Yossif and Ebied 2015; Musa and Gisilanbe 2017) also confirmed that the slope gradient was significantly affected soil clay and sand contents. Thus, the variation might be due to the selectively transportation process during water erosion where fine particles have been carried away toward the lower slope. Similarly, (Khan *et al.* (2013); Nnabude *et al.* (2016); Hishe *et al.* (2017) and Yasin and Yulnafatmawita (2018) stated that clay and sand contents were significantly different at different slope classes.

On the other hand, a silt particle was not significantly ($P > 0.05$) affected by the slope gradient (Table 2). However, the higher silt content was observed at the middle slope and the least content was obtained at the upper slope. Different scholars (Gebrelibanos and Assen 2014; Miheretu and Yimer 2018; Liu *et al.* 2020) also confirmed that sand and clay contents, but not silt content significantly differed among slope positions.

Soil bulk density, moisture content, particle density, and total porosity

The analysis of variance reflected that slope gradient significantly ($P < 0.01$) affected soil bulk density, moisture content, particle density, and total porosity (Table 2). The highest bulk density (1.40gm/cm^3), the medium (1.22gm/cm^3), and the lowest (1.14gm/cm^3) were recorded at the lower, middle, and upper slopes, respectively. While, the highest soil moisture content, particle density, and total porosity (19.81%, 2.54gm/$cm^{3,}$ and 51.85%), the medium (16.73%, 2.25gm/$cm^{3,}$ and 44.44%) and the lowest (10.52%, 1.94gm/cm^3 and 26.68%) were obtained at lower, middle and upper slopes class, respectively (Table 2). The mean separation also showed that soil bulk density, moisture content, particle density, and total porosity were significantly different in each slope class.

This finding agreed with (Aytenew 2015) who stated that the effects of slope gradient on soil bulk density and total porosity were significant. Thus, these variations among the slope gradient might be attributed to the variation of soil particle size distribution and disturbance of soil particles by severe erosion. The result is also supported by Hailu *et al.* (2012) and Khan *et al.* (2013) who found soil bulk density, moisture content, and particle density were significantly affected by slope positions. The result also showed that soil bulk density has a direct, particle density and moisture content inverse relation with slope gradient. Similarly, Mekonen and Tesfahunegn (2011) confirmed soil moisture content, total porosity and particle density were significantly affected by slope gradient. This could probably be the fertile fine soil particles and organic matter contents were removed from the upper slope and get deposited in the lower slope positions.

Soil pH, organic carbon, and cation exchange capacity

In respect to slope gradient, soil pH, organic carbon and cation exchange capacity were significantly ($P < 0.01$) affected (Table 2). The highest soil pH, organic carbon and cation exchange capacity (6.65, 2.53% and 48.90cmol (+) kg^{-1}), the middle (6.35, 1.86% and 43.10cmol (+) kg^{-1}) and the lowest (6.10, 1.83% and 35.17cmol (+) kg^{-1}) were noted at upper, middle and lower slope class, respectively. The mean separation also showed soil pH and cation exchange capacity were showed significant variations in each slope class. Similarly, Beyene (2017) and Liu *et al.* (2020) reported that soil pH and cation exchange capacity showed a significant difference among different slope gradients. This is due to the removal of bases from the higher slope gradient and their accumulation on moderate and gentle slopes. While organic carbon reflected significant variations between lower slope class with upper and middle slope classes (Table 2).

Soil with a large amount of clay and organic matter has a larger cation exchange capacity than sandy soil with low organic matter (Miheretu and Yimer 2018; Babur *et al.* 2021). Hence, soil encompassing high clay content at the lower slope has a high pH and cation exchange capacity (Ito and Wagai 2017). According to Yossif and Ebied (2015) and Addis *et al.* (2016a) slope gradient had significant effects on soil pH, organic carbon, cation exchange capacity, and total nitrogen. This is due to the steeper the slope, the higher the runoff, and the greater the relocation of soil materials downslope through rainfall-driven erosion.

Soil total nitrogen, available phosphorus, and available potassium

The analysis of variance showed that the slope gradient significantly ($P < 0.01$) affected soil total nitrogen and available phosphorus but not available potassium (Table 2). Even though available potassium did not show a statistically significant difference due to the slope gradient, the mean value increased down the slope. The highest (0.18%, 8.01ppm and 0.45cmol (+) kg^{-1}), the middle (0.15%, 5.23ppm and 0.52cmol (+) kg^{-1}) and the lowest (0.14%, 2.80ppm and 0.45cmol (+) kg^{-1}) total nitrogen, available phosphorus and available potassium were recorded at lower, middle and upper slope classes, respectively. The mean separation also showed that soil total nitrogen of the lower slope class had been significantly different from the middle and upper slope classes meanwhile, available phosphorus is significantly different in each slope class.

This finding agreed with (Akbari *et al.* 2014; Musa and Gisilanbe 2017) who stated that slope positions indicated a significant difference in soil total nitrogen and available phosphorus. This might be due to the reduction of soil organic matter content and crop residue removal by the action of soil erosion from the upper slope gradient. Similarly, Akbari *et al.* (2014) and Gebrelibanos and Assen (2014) stated that slope position had significant effects on soil total nitrogen and available phosphorus, whereas, available potassium is not significantly different across slope position (Asadi *et al.* 2012).

Table 2
Effects of slope gradient on selected soil physicochemical properties in the study watershed

Slope classes	Parameters												
	Clay (%)	Silt (%)	Sand (%)	BD(gm/cm^3)	MC (%)	PD(gm/cm^3)	TP (%)	pH (H_2O)	OC (%)	CEC(cmol (+)kg^{-1})	TN (%)	Ava.P (ppm)	Ava.K(cm ^{1})
Upper (30–60%)	35.50b	33.50	31.00a	1.40a	10.52a	1.94a	26.68a	6.10a	1.83a	35.17a	0.14a	2.80a	0.53
Middle (15–30%)	37.67b	35.67	26.67b	1.22b	16.73b	2.25b	44.44b	6.35b	1.86a	43.10b	0.15a	5.23b	0.52
Lower (10–15%)	41.67a	34.50	23.83c	1.14c	19.81c	2.54c	51.85c	6.65c	2.53b	48.90c	0.18b	8.01c	0.45
LSD(0.05)	3.22	Ns	2.49	0.03	2.27	0.13	3.98	0.05	0.26	0.95	0.02	1.04	Ns
CV (%)	9.95	10.75	10.82	12.97	17.10	16.71	11.46	8.60	14.61	12.64	12.00	22.92	19.59

BD = Bulk density, MC = Moisture content, PD = Particle density, TP = Total porosity, CEC = Cation exchange capacity, Total nitrogen, Ava.P = Available Phosph
Ava.K = Available Potassium, OC = Organic carbon, LSD = List significant difference, CV = Coefficient of variation

Effects of SWC measures and slope gradient on selected soil attributes

Soil texture

The analysis of variance revealed that clay and silt content were highly significant ($P < 0.01$) and sand content was significantly ($P < 0.05$) affected by the interactions of SWC measures and slope position. The highest clay content (53.33%) was obtained from the lower slope position under soil bund while the lowest (34.00%) was obtained from non-conserved and stone-faced soil bund under upper and middle slope class (Table 3). The higher silt content (41.33%) was measured at middle slope class under soil bund, and the lower (28.00%) was recorded at lower slope under soil bund. Whereas, the highest sand content (36.00%) was obtained from the upper slope position under non-conserved fields and the lowest (18.67%) was from the lower slope position under soil bund (Table 3). The mean separation also showed that silt, and sand contents in each slope class and most treatments of clay content at upper and lower slope position had shown significant variations. Similarly, Challa *et al.* (2016) found that the interactions of SWC measures and slope position were significantly affect soil texture. This is due to the selective removal of fine and more fertile topsoil fractions from the upper slope class and the accumulations towards the lower slope classes.

Soil bulk density, moisture content, particle density, and total porosity

The analysis of variance revealed that soil bulk density, moisture content, particle density, and total porosity were not significantly ($P > 0.05$) affected by the interactions of slope position and conservation measures (Table 3). However, the lowest bulk density and highest moisture content were recorded from the lower slope under SFSBG followed by SB while the highest bulk density and lowest moisture content were recorded from the upper slope under the non-conserved field (Table 3). Similarly, the highest total porosity was obtained from the lower slope under SFSBG followed by SFSB (Table 3). The highest soil particle density was observed at lower slope under soil bund and stone-faced soil bund stabilized with Kidan grass while the lowest was observed at upper slope under non-conserved land (Table 3). A similar result was reported by Mengistu *et al.* (2016) who documented that soil bulk density, moisture content, and total porosity did not show significant variation due to the interaction of SWC measures and slope position.

Soil pH, organic carbon, and cation exchange capacity

The analysis of variance reflected that soil pH and organic carbon were significantly ($P < 0.05$) affected by SWC measures and slope gradient interaction effects (Table 3). The highest soil pH and organic carbon (6.75 and 2.89%) and the lowest (6.03 and 1.02%) were recorded at lower slope under stone-faced soil bund stabilized with Kidan grass and upper slope without conservation measures respectively. The result is in agreement with (Hailu *et al.* 2012; Bekele *et al.* 2016) who stated that soil pH was showed a significant difference due to SWC measures and slope position interaction. This is due to conservation structures might be trapped fine clay particles and decreased the loss of basic cations through leaching. Similarly, Gebrelibanos and Assen (2014) confirmed that the interaction of SWC measures and slope position significantly affect soil organic carbon distribution.

On the contrary, the analysis of variance showed that soil cation exchange capacity was not significantly ($P > 0.05$) affected by the interaction of SWC and slope gradient (Table 3). However, the highest cation exchange capacity was observed at the lower slope with stone-faced soil bund stabilized with Kidan grasses and the lowest at the upper slope with non-conserved land (Table 3). On the contrary, Gadana *et al.* (2020) confirmed that soil cation exchange capacity was shown a significant difference due to combine effects of SWC measures and slope position.

Soil total nitrogen, available phosphorus, and available potassium

The analysis of variance result reflected soil total nitrogen and available potassium did not show a significant (P > 0.05) variation in respect to SWC measures and slope gradient interaction (Table 3). However, the highest total nitrogen (0.19%) was observed at the lower slope under conserved lands, while the lowest (0.12%) was recorded in the middle and upper slope under non-conserved land. The highest available potassium (0.69 cmol (+) kg^{-1}) was measured at the lower slope under stone-faced soil bund stabilized by Kidan grass and the lowest (0.33cmol (+) kg^{-1}) was observed at the upper slope under non-conserved land. Different scholars, (Mengistu *et al.* 2016; Teressa 2017) confirmed that soil total nitrogen and available potassium did not show significant variation due to the interaction of SWC measures and slope position.

Meanwhile, soil available phosphorus had shown a significant (P < 0.05) variation as a result of the interaction effects of SWC and slope gradient (Table 3). The highest available phosphorus (11.59ppm) was obtained from lower slope class under soil bund and the lowest (1.50ppm) was measured at upper slope classes under non-conserved land (Table 3). This result was in correspondence with (Bekele *et al.* 2016) who stated that under SWC technologies the available phosphorus was significantly higher in the lower slope than in the mid-slope. The higher content of available phosphorus under SWC is probably due to SWC measures are reduce slope angle and runoff length.

Table 3
Effects of SWC measures and slope gradient on selected soil physicochemical properties in the study watershed

Slope classes	Conservation measures	Parameters										
		Clay (%)	Silt (%)	Sand (%)	BD(gm/cm^3)	MC (%)	PD(gm/cm^3)	TP (%)	pH (H_2O)	OC (%)	CEC(cmol (+) kg^{-1})	TN (%)
Upper (30–60%)	C	34.00c	30.00de	36.00a	1.63	5.62	1.74	5.90	6.03e	1.02e	29.65	0.12
	SFSB	43.33b	31.33cde	25.33de	1.39	9.29	1.98	29.48	6.12de	1.90c	36.20	0.14
	SFSBG	37.33bc	36.67abc	26.00cde	1.28	14.23	2.10	38.84	6.17d	1.91c	37.73	0.14
	SB	35.33c	33.33bcde	31.33ab	1.31	12.93	1.94	32.51	6.08de	2.48ab	37.09	0.14
Middle (15–30%)	C	37.33bc	32.00bcde	30.67abc	1.48	11.63	1.92	22.91	6.15d	1.35de	36.90	0.12
	SFSB	34.00c	38.00ab	28.00bcd	1.21	16.30	2.30	47.61	6.43b	1.53cd	44.17	0.15
	SFSBG	37.33bc	36.00abcd	26.67bcde	1.07	19.71	2.44	55.22	6.48b	2.53ab	46.54	0.17
	SB	35.33c	41.33a	23.33def	1.12	19.28	2.35	52.02	6.33c	2.02bc	44.78	0.17
Lower (10–15%)	C	42.00b	35.33abcd	22.67ef	1.33	15.78	2.02	33.85	6.43b	1.71cd	44.48	0.13
	SFSB	34.67c	34.67bcd	30.67abc	1.13	17.86	2.63	56.90	6.70a	2.75a	50.65	0.19
	SFSBG	34.67c	38.00ab	27.33bcde	1.05	24.72	2.75	61.72	6.75a	2.89a	50.72	0.19
	SB	53.33a	28.00e	18.67f	1.06	20.88	2.76	54.94	6.70a	2.75a	49.74	0.19
LSD (0.05)	6.91	6.29	4.98	4.98	Ns	Ns	Ns	Ns	0.09	0.51	Ns	Ns
CV (%)	9.95	10.75	10.82	10.82	12.97	17.10	16.71	11.46	8.60	14.61	12.64	19.5

BD = Bulk density, MC = Moisture content, PD = Particle density, TP = Total porosity, CEC = Cation exchange capacity, Total nitrogen, Ava.P = Available Phospho Potassium, OC = Organic carbon, C = Non-conserved, SFSB = Stone faced soil bund, SFSBG = Stone faced soil bund stabilized with kidan grass, SB = Soil bunc difference, CV = Coefficient of variation

Conclusions

Soil and water conservation measures affect the selected soil physicochemical properties in the study watershed. Most of the observed soil physicochemical properties were significantly higher in stone-faced soil bund stabilized with kidan grass followed by soil bund and stone-faced soil bund while lower soil attributes were observed at the non-conserved agricultural land. Similarly, the slope gradient affected most of the measured soil physicochemical properties. The majority of soil properties were significantly higher in the lower slope followed by the middle while significantly lower soil properties were recorded at the upper slope class. The interactions of slope gradient and SWC measures affect soil texture; pH, organic carbon, and available phosphorus but do not affect soil bulk density, moisture content, particle density, total porosity, cation exchange capacity, total nitrogen, and available potassium. Therefore, in the study watershed and other similar agro-ecologies, farmers should use integrated SWC measures to avert the rainfall-driven soil nutrient loss. In addition, the local farmers should also use the upper slope class (> 30%) areas for tree planting instead of crop production. Finally, to bring the physical SWC measures fully efficient it should be integrated with multipurpose plant species and organic amendments.

Declarations

Conflict of interest:

There is not any direct or indirect conflict of interest in this manuscript and its data.

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Figures

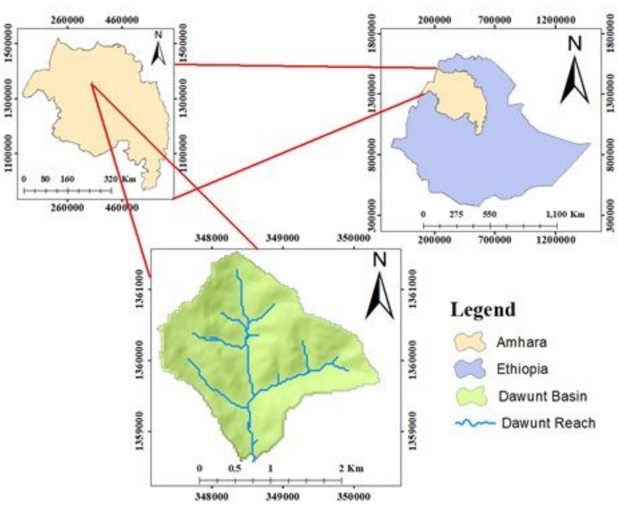

Figure 1

Location of Dawunt watershed in north western Amhara Region, Ethiopia.