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The impact of structural land management measures on soil physical and chemical properties at Yirgachafe district, Gedeo Zone, Ethiopia.

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Abstract: *Land degradation due to soil erosion is the main environmental problem in Ethiopia. To reduce the problem, structural land management measures have been employed over the past two decades through government led community mobilization. This study was conducted with the main objective to evaluate the impact of structural land management practices on soil physical and chemical properties in Chelba and Tutetekebele's/Peasant associations (PAs) of Yirgachafe district. From each kebele fields managed with soil bund and unmanaged fields were used for the study. 72 soil samples (36 from managed and 36 from unmanaged fields) considering three sampling positions 5cm, 2m and 5m were collected to analyzesoil texture, bulk density, moisture content, soil pH, Carbon, TN, Av.P, Av.K, and CEC. To analyze bulk density 36 separate undisturbed soil samples were also collected for using a core sampler. All collected soil samples were analyzed using standard and recommended methods. Using the R software package, the effect of independent variables (land management structure and sample position) on the dependent variables (soil physicochemical properties) was statistically tested. The significance test was done using ANOVA. The findings indicated sand and silt fractions were significantly higher in unmanaged farm fields than managed fields, and showed significant increase when the sampling point far from the soil bund in 5cm to 5m. But, the clay fraction was significantly higher in managed farm field by soil bund than unmanaged and showed significant decrease when the farness increased from 5cm to 5m. Soil moisture, pH, organic carbon, total nitrogen, phosphorus and cation exchange capacityof soil were significantly higher in farm fields managed by soil bund at $p<0.05$. While Bulk density was significantly higher in unmanaged farm field than managed.The effects of structural land management measures were significant in almost all soil physicochemical properties at $P < 0.01$ except for the sand, silt content and bulk density in farm fields. The study findings revealed that soil bund structural land management measure is by far the most effective, and recommended method to mitigate soil erosion, and refining soil physical and chemical properties in the Tutete and Chelbakebele's of Yirgachafe district. Therefore, governmental and non-governmental stakeholders should work together to strengthen and sustain the implementation process of the structural land management measures*

Keywords: *Land degradation, soil bund, soil erosion, structural land management, soil physical and chemical properties*

1. INTRODUCTION

1.1. Background and Justification

Soil erosion is one of the most serious worldwide environmental challenges, with both local and global implications. It has accelerated in most regions of the world, particularly in emerging countries, due to many socioeconomic and demographic reasons, as well as limited resources (Eswaran et al., 2001). According to Eswaranet al. (2001), the global yearly loss of soil due to natural and anthropogenic sources is 75 billion tons per year. Soil erosion will continue to be a major global issue in the twenty-first century due to its detrimental consequences on agronomic productivity, the environment, food security, and quality of life.

Land degradation caused by soil erosion has serious effects, including environmental hazards, extended food shortages, economic losses, poverty, and migration (Hurni et al., 2010). Land degradation not only has an impact on farm output and regional economy, but it also reduces biodiversity and increases reservoir sedimentation, limiting water resource storage and quality

(Shiferaw and Holden, 1999; Taddese, 2001). Furthermore, land degradation diminishes land and water resources' potential to provide long-term ecological services (Baptista et al., 2015b).

Two of the most common causes of diminishing agricultural output are soil erosion and nutrient depletion. Soil erosion has been associated to low and deteriorating crop yields in empirical investigations (Troeh et al., 1991). Crop output drops in part due to the loss of vital organic matter and plant nutrients. Eroded soils are also deficient in moisture.As soil erosion became more severe and soil fertility and output declined in the 1970s and 1980s, the Ethiopian government and development partners made significant efforts to implement and improve SWC technologies (Adimasu, 2018), but the approach was top-down. However, improving soil physicochemical properties and ensuring SWC solutions for rural livelihoods has recently emerged as one of the most essential policy goals (Bojago et al., 2023). Ethiopia must prioritize the management of its soil and water resources because agriculture employs a substantial portion of the local population. However, our current understanding of soil fertility management is inadequate to support the vast majority of farmers who rely on the soil for a living, either directly or indirectly.Farmers are currently using SWC conservation practices to avoid soil erosion across the country. However, because the extent of the intervention, the number of personnel needed, and the potential rewards vary by region, so does the execution (Silash et al., 2019).

The Ethiopian government launched watershed control operations through community mobilization. Following this, structural land practices were applied in various watersheds of the southern region, particularly the district of Yirgachafe. Several studies on SWC have been conducted throughout the country, with the bulk of them taking place in arid areas (Bojago et al., 2023). Despite the fact that the practices were applied in several watersheds of the Yirgachafe district, the problem of soil erosion remains the largest obstacle, and the efficiency of the land management measures done in the area has not been fully examined.Due to farmers' lack of information about the impact of structural land management on soil property enhancement and erosion control, the created structures were subjected to destruction, maintenance issues, and failure. No study has been conducted to assess the impact of applied structural land management on educating and convincing farmers in the study area, as well as providing information to stakeholders. As a result, the primary goal of this study was to assess the impact of structural land management approaches on soil physical and chemical properties.

2. METHODOLOGY

2.1. Description of the study area

The research was carried out in the Yirgachafe district, which is part of the Gedio Zone. Geographically, the district is located at latitude 6006'0"N and longitude 38009'0"E to 38°31'0". Gedio Zone and Yigrachafe District with altitudes ranging from 1477 to 3068 m.a.s.l. and 1601 to 2844 m.a.s.l., respectively. The district's total area coverage is 224 km2. The topography ranges from flat to somewhat hilly. The agro-ecology district is divided into two sections: midland (Woinadega) and highland (Dega). Tutete and ChelbaKebele are two of the district's 27 peasant associations (Kebele). The soil in the district is black and reddish. The district had a total population of 236,788, with 117,673 women and 119,115 men. The area is primarily covered by agroforestry practices based on coffee, enset, and fruit. Annual crops grown in the area were pea, wheat, barley, maize, teff, and bean.

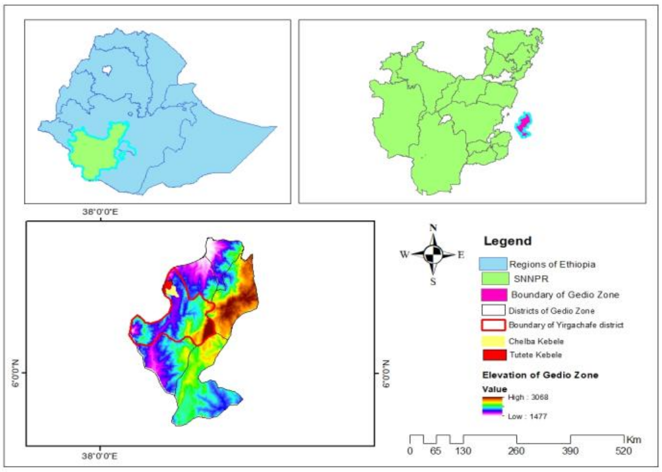

Figure1. *Study area map*

Research Design

In this study, sample managed and unmanaged areas from the two kebeles were chosen based on the implementation status of land management strategies. The soil bund and fanyaaju structures were chosen at random from a controlled site (a field with structural land management approach). A complete randomized block design (RCBD) test was used. In the selected farm plots, the experimental plots for each treatment (managed and unmanaged farm lands) were duplicated three times.

2.2. Data collection and statistical analysis

All necessary data was collected from the field. The study kebele and district were chosen based on the presence of farmland management structures. Following the selection of the district and Kebele, the sample soils were gathered from a farm field with a soil bund. The R software package was used to analyze the collected data.

3.2.1. Soil sampling technique and Analysis

To determine representative soil sampling plots/structures and sites, a preliminary survey was conducted. The study included structures that were more than five years old. To obtain disturbed and undisturbed soil samples, an augur and a core sampler were employed, respectively. Before collecting soil samples, sampling positions were determined by measuring distances starting from the structures in order to assess the influence of structural land management structures per position. The spots were marked in 5m, 2m, and 5cm distances from the structure. In other words, fields where the soil detached/lost were 5m away from the structure, the soil transport was 2m away from the structure, and the soil deposit was 5cm away from the structure.

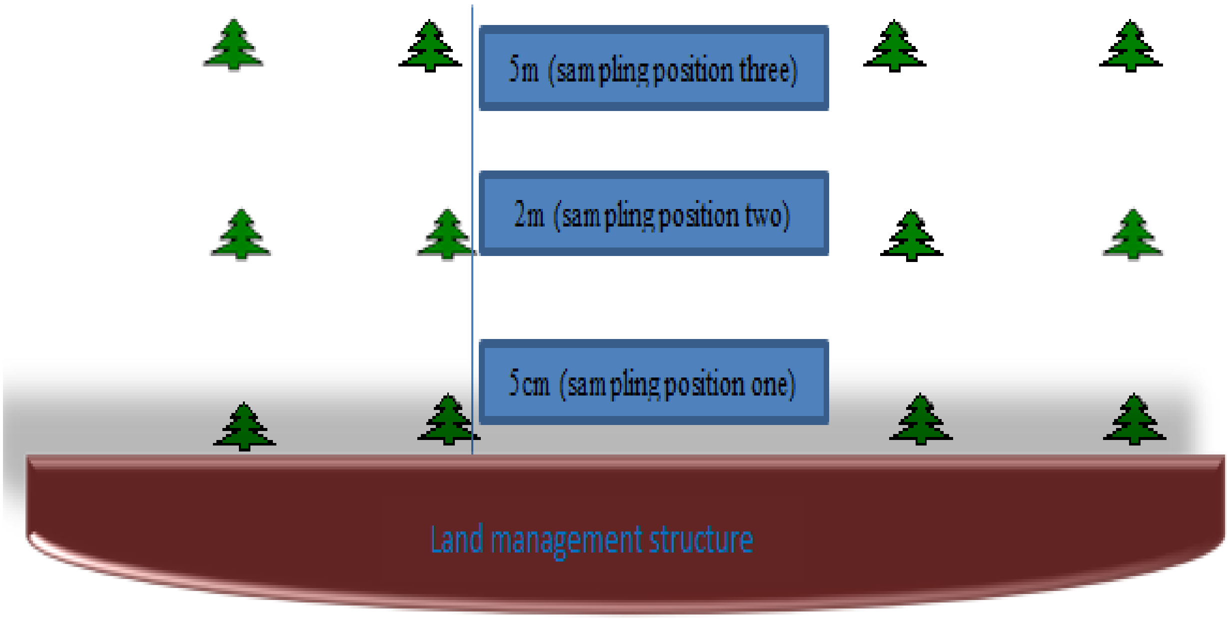

Figure2. *Pictorial representation of soilsampling points from the soil bund displayed by tree picture and sampling positions*

Composite soil samples were taken from managed (with soil bunds) and unmanaged (without soil bunds) farmlands from three positions (5cm, 2m and 5m far from each structure) between three replicated structures. From each sampling position four samples were collected and composited into two samples. Soil samples from the same position were mixed together to form a composite sample. This means two composite samples were collected from each position for analysis. Thirty-six soil samples were collected from managed and unmanaged lands. The 18 samples were from three replicates of managed field and 18 soil samples were from unmanaged fields.Totally of 72 samples were collected from two study kebele's. The samples were collected by from 0-20cm depth using augur. The collected composite soil samples were analyzed for selected Physico-chemical properties: soil texture, bulk density, moisture content, soil pH, Carbon, TN, Av. P, Avail K, and CEC. To analyze bulk density 36 separate undisturbed soil samples were also collected for using a core sampler. The fresh weight of each sample was measured in the field using sensitive balance, and then the collected soils were oven dried at the soil laboratory to get the dry weight of soil samples.

Soil laboratory Analysis

The collected soil samples were analyzed at Soil and Plant Analysis Laboratory of Southern Agricultural Research Institute.Soil sample analysis for the collections was made using standard soil analysis procedures. Soil texture was analyzed with Bouyoucos hydrometer as described by Day (1965), Bulk density was analyzed with gravimetric as suggested by Blake and Hartge (1986), pH was analyzed with pH meter as described by Thomas (1996), Moisture content was analyzed by the gravimetric method as described by Shukla*et al*. (2014), Soil organic carbon (SOC %) was analyzed using the procedure suggested by Walkley and Black (1934), Kjeldahl method was used to measure totalnitrogen (Bremner and Mulvaney, 1982), Available phosphorus was analyzed by using Olson extraction method and spectrophotometer (0.5 M $NaHCO_3$) (Olsen and Sommers, 1982), available potassium was analyzed by using Jenway PFP7 flame photometer method (Rowell, 1994) and Cation Exchange Capacity was analyzed by summation method (Chapman, 1965).

3. Results and Discussion

3.1. The effect of structural land management practices on selected soil physical properties

Structural land management measures implemented in the study area had improved the soil nutrients as a result of a reduction in runoff and sediment transport. This was indicated by the significant variations in soil physicochemical properties between managed and unmanaged areas. The structures also decreased the slope length and steepness and consequently led to better infiltration, slow movement, and less accumulation of runoff. As a result, the removal of soil particles, crop residues, and other organic components was limited, which improved the soil condition as compared to the unmanaged soils.

3.1.1. Soil texture (Particle size distribution)

The textural class of the soil was revealed to be clay dominant in both in the managed and unmanaged areas of the Yirgachafe district**.** Soil texture fractions of clay, silt, and sand showed significant variation withtreatments (p=0.03, 0.02 and 0.04 respectively). The proportion of sand in soil under theunmanaged areas was significantly higher compared to the managed lands. It decreasedprogressively from the 5m to 5cm zone of the constructed structure. Conversely, the clay fractionwas significantly higher managed compared to unmanaged farmlands. The values increased from5m to 5cmin the managed farmland. The proportion of silt was significantly higher inunmanaged farmland than managed areas.

The particle size fraction of the soil was fine-textured in both managed and unmanaged soils. The soil in the research area was dominated by clay content, indicating a substantially higher mean value in managed areas. Similarly, Mengistu et al. (2016) found higher mean clay concentration in the treated Minchit sub-watershed than in the untreated Zikire sub-watershed. Higher soil erosion, removal of fine materials, clay contents, and organic matter could all be explanations for considerably lower clay concentration in untreated areas. Clay contents include fine particles that are more prone to erosion unless treated with SWC methods (Hishe et al., 2017; Selassie et al., 2015). Clay soil has a high water and nutrient retention capacity and a low level of leaching Osman (2013). It is obvious from the following that the soil in the treated region has more finer fractions, clay, and silt, and less coarse sand fractions. A scenario like this is preferable in terms of soil fertility since the finer soil fraction retains nutrients and water.

Table1. *ANOVA values of soil Physical properties*

Source of variation	Sand		Silt		Clay		Moisture		Bulk density	
	Ms	P value	Ms	P value	Ms	P value	Ms	P value	Ms	P value
Management	59.095	0.04	27.392	0.02	194.370	0.03	32.527	0.00	0.019	0.05

status										
Position	0.087	0.05	11.831	0.02	12.220	0.04	12.087	0.05	0.009	0.01
Mgt*position	9.857	0.02	3.760	0.04	10.612	0.012	1.055	0.00	0.010	0.05
Error	1.813		1.120		1.881		0.593		0.057	

Note: Ms is mean square, Mgt is management status, P is the significance

The unmanaged area is subject to soil erosion and removal of finer soil fractions with runoff water. This nature of the soil makes the area to be less productive because the area faced high soil erosion, continuous cultivation, and other natural and manmade influences. My findings contradicted the findings of Muktar et al. (2020), who discovered that non-conserved land soils had the highest % clay content compared to conserved land soils. The highest clay level in the control treatment may be attributed to tillage exposing the soil and water erosion exposing the subsoil, which is naturally high in clay content. Complete topsoil removal at the loss zone causes clay-dominated subsoil to flow down the slope and deposit on the fertile accumulation.Unconserved agriculture plots had the greatest mean value of sand concentration. Sirna and Leta (2020) found a substantial variation in soil particle percentage of sand content between conserved and non-conserved farmlands. Farmland managed with a soil bund had the highest mean value. However, silt and clay content did not differ significantly across conserved and non-conserved farmlands. Because soil texture is not modified by conservation efforts in such a short period, the difference in sand content could be attributed to inherent soil properties derived from the parent material.

3.1.2. Bulk density

The soilbulk density was significantly (p =0.05) higher under unmanagedfarmland compared to the managed one. The unmanaged area had removed the finer soil fraction, raising the value of bulk density. Conversely, the soils having structural land management P had less erosion and more proportion of clay and silt, lowering the value of bulk density.

Structural land management practices affected the bulk density of the soil in the Gumara watershed. A relatively higher bulk density in non-conserved plots could be related to washing out of fine organic matter-rich soils by erosion and thereby exposing slightly heavier soil particles (Belayneh et al., 2019). On the other hand, several potential causes may explain lower bulk density in conserved plots such as lesser effects of soil erosion (structural land managementstructures as a barrier) and relatively higher soil organic matter content resulting from the accumulation of crop residues decay, plant leaves’ decay, and less vulnerability for easy removal of this component. The findings of the study were congruent with those of Hishe et al. (2017) and Hailu et al. (2012) for the Middle Silluh valley in northern Ethiopia and the Goromti watershed in western Ethiopia, respectively. Challa et al. (2016), Husen et al. (2017), and Selassie et al. (2015), on the other hand, found that treated samples had a statistically significantly lower bulk density than untreated ones. Similarly, the non-conserved farm plot had the highest mean value of bulk density compared to the conserved farm plots. The conserved farm plot had a much lower mean bulk density value than the unconserved farm plot. The greater bulk density readings in the unconserved farm plots could be attributed to erosion exposing the subsoil and the removal and oxidation of organic carbon from the topsoil. Soil erosion caused by runoff and the decomposition of a very modest amount of organic carbon decreased soil structural characteristics, resulting in increased bulk density (Muktar et al., 2020).

Table2. *The mean value of each soil's physical properties in managed and unmanaged areas*

Physical properties	Treatment status		P-value	Soil sample position			P-value
	Managed	Unmanaged		5m far from the structure	2m far from the structure	5cm far from structure	
SAND	31.7	37.9	0.04	34.8	34.6	35	0.05
SILT	19.1	23.4	0.02	23.5	21.6	18.7	0.02
CLAY	49.2	37.8	0.03	41.7	42.6	46.3	0.04
MOIST	21.4	16.7	0.00	16.8	18.6	21.7	0.05
BD	1.2	1.3	0.05	1.2	1.2	1.3	0.01

3.1.3. Moisture content

The moisture content of the soil in managed fields was significantly (p=1%) higher than in unmanaged soil. Higher values were obtained in the structure's lower position in the managed area. Similarly, the moisture value was raised from the upper to the lower position. The conservation methods' influence on water storage in the soil profile could explain such an increase in soil moisture.

3.2. Effects on soil chemical properties

3.2.1. Soil pH (soil reaction)

The pH value on unmanaged soils was significantly (p=0.0001) lower than on managed soils. The reduction in soil pH in soils with no conservation practices was most likely caused by the loss of basic cations as fine soil fractions eroded. On the contrary, soils maintained by certain conservation methods would retain basic cations as well as fine fractions, elevating soil pH.In the managed area, soil pH had slightly higher mean values. High rainfall may be connected with leaching and removal of key soil nutrients, resulting in relatively increased soil acidity in unmanaged regions. According to Amare et al. (2013) and Osman (2013), a large volume of rainwater leaches soluble bases and so contributes to soil acidity. Similarly, long-term agriculture, excessive rainfall, topographic steepness, and inorganic fertilizer application are all likely to increase soil acidity (Selassie et al. 2015). Challa et al. (2016) and Husen et al. (2017) found similar results in Ethiopia's central highlands.

3.2.2. Organic Carbon (OC)

Organic carbon content was significantly (p=0.0034) affected by managed and unmanaged farmlands. The lands with management practices that provide mechanical barriers to the runoff water would have reduced the loss of fine soil fractions and organic carbon. There was also a significant variation (p=0.0012) between sampling positions. Conservation strategies had a considerable impact on organic carbon and total nitrogen in the research region. This is consistent with the findings of Challa et al. (2016), Hailu et al. (2012), Hishe et al. (2017), Selassie et al. (2015), and Sinore et al. (2018), all of whom found statistically significant increases in soil organic carbon in treated landscapes. It may be related mostly to conservation structures and biomass buildup (Selassie et al. 2015). Soils subjected to severe erosion are more prone to the decomposition of soil organic carbon than soils subjected to minor erosion (Abegaz et al. 2016). This means that non-conserved soils are more prone to erosion and have lower soil organic carbon concentrations than conserved soils.

The variation is primarily explained by conservation effects on soil erosion; because structural land management structures reduce the loss of fine soil particles and residues (Husen*et al*. 2017; Mengistu*et al*. 2016; Selassie *et al*. 2015; Sinore*et al*. 2018). This procedure improves the concentration of soil organic matter and soil organic carbon which consequently resulting increase in TN in the soil. Challa et al. (2016), Hailu et al. (2012), Husen et al. (2017), Selassie et al. (2015), and Sinore et al. (2018) all reported that the treated region had significantly greater total nitrogen content. According to the study, SWC measures found that the total nitrogen was considerably changed by treatment status. When compared to treated cropland, it was much lower in untreated areas. This was similar to previous research (Sinore et al. 2018).

3.2.3. Total Nitrogen (TN)

According to the research finding the total nitrogen amount was significantly (p=0.0075) affected by treatment status by SWC measures. It was significantly lower in unmanaged areas compared to managed farmland. Moreover, the value was higher in the 5cm distancefrom the structure structure than in the 2m and 5m distance from the structure with a significance level of (0.0030). The increases in N content under structural land management were due to minimum loss of fertility bearing soil fractions such as clay and silt. The soil structural land managementpractices that reducing runoff and soil loss and enhancing profile water storage would enhance crop growth and contribute to OM and N input in the soil.

Table3. *Significant variations (ANOVA) of soil chemical properties on treatment status and sample position*

Source of	pH	OC	T	P	CEC	K

variation	Ms	P value	Ms	P value	Ms	P value	Ms	P value	Ms	P value	Ms	P value
Management status	0.407	0.0001	0.033	0.0034	0.0002	0.0075	2.430	0.0053	55.990	0.0001	0.173	<.0001
Position	0.063	0.236	0.078	0.0012	0.033	0.003	0.385	0.0004	0.502	0.0001	0.014	0.0001
Treat*Posi	0.010	0.0012	0.045	0.001	0.0004	0.0578	0.002	0.0032	10.420	0.0001	0.011	0.05
Error	0.002		0.014		0.0001		0.180		2.100		0.002	

Note: pH=acidity level, OC=organic carbon, TN=total nitrogen, P=available phosphorus, CEC=cation exchange capacity, K= available potassium.

Table4. *The mean value of each soil chemical property in managed and unmanaged areas*

Soil chemical properties	Treatment Status		Soil sample position		
	Managed	Unmanaged	5m far from the structure	2m far from the structure	5cm far from structure
pH	5.70a	5.30b	5.56a	5.49a	5.51a
OC%	1.49a	1.13b	1.34b	1.47ab	1.52a
TN%	0.12a	0.10b	0.11b	0.12ab	0.13a
Ppm	22.17a	21.26b	21.71b	21.53b	22.00a
CEC (meq/100gm)	22.44a	18.12b	20.90a	20.33a	19.62b
K (meq/100gm)	1.13a	0.89b	1.04a	1.012a	0.97b

Note: pH=acidity level, OC=organic carbon, TN=total nitrogen, P=available phosphorus, CEC=cation exchange capacity, K= available potassium.

3.2.4. Soil Phosphorus Available

The soil available phosphorus was significantly affected by physical soil and water conservation measures. All the structural land management practices indicated significantly (0.0053) higher contents of Av.p than in unmanaged areas. The higher Av.P values were observed in the 5cm position of the structure, but the lowest content was observed at a 5m of the structure. The available phosphorus content of the soil differed significantly between managed and unmanaged areas. This finding contradicts the findings of Hishe et al. (2017) for the Middle Silluh valley in Northern Ethiopia. According to Hailu et al. (2012), there was no statistically significant difference between treated and untreated fields. Our findings were consistent with those of Mengistu et al. (2016) and Selassie et al. (2015), who found greater accessible phosphorus concentrations in treated soils. The av. P concentration in the soil in the research area was insufficient. This could be explained by a number of factors including the soil's medium acidity and soil erosion from runoff, which may contribute to its restricted availability in the soil. The soil's inadequate availability of phosphorus may hinder plant growth and productivity in the area. Phosphorus in the soil is significantly required by plants and, when present in low concentrations, can induce delayed growth (Hishe et al. 2017). In general, fluctuations in accessible P contents in soils should be connected to the intensity of soil weathering and P fixation, as well as the level of Physical or mechanical SWC methods retaining/adding mineral and organic fractions in soil.

3.2.5. Cation Exchange Capacity (CEC)

Structured land management methods also have a major impact on exchangeable cations (K, Ca, Mg, Na, Fe, Zn, Mn, and Cu). Overall, the mean values of all captions were significantly (p=0.0001) higher under-managed structure area than unmanaged structure area. The value also indicates the structure's decrease from a 5m location to a 5cm position with a significance variation level (p=0.0001). The soil in the watershed was found to have a high CEC content. This could be attributable to the soil's natural qualities, as fine-textured soils have a more exchangeable base (Osman 2013). Soils with high clay and SOM content are more likely to store positively charged ions, resulting in high CEC concentrations (Selassie et al. 2015; Sinore et al. 2018). Structured land management approaches resulted in treated soils having a higher CEC and cation exchange capacity than untreated soils. According to different researchers, the influence of SWC measurements on soil CEC concentration was non-significant (Hailu et al. 2012; Hishe et al. 2017). Challa et al. (2016), Mengistu et al. (2016), and Selassie et al. (2015), on the other hand, found considerably increased CEC concentrations in treated soil. The disparity between research reports could be related to differences in the efficiency of SWC measures due to differences in conservation types, correct design, and upkeep. Sinore et al. (2018) found that soil treated with sesbania and elephant grasses had considerably greater CEC and exchangeable bases than control soil. Supporting terracing with such plants/grasses reinforces the bund, generates high biomass, increases organic matter, and improves erosion management, resulting in increased CEC in the soil. Both clay and colloidal organic materials have the ability to absorb and retain positively charged ions. Soils with a high clay and organic matter concentration have a high CEC.

3.2.6. Potassium (K)

According to the research findings, physical soil and water conservation techniques had a substantial impact on soil potassium. The results demonstrate that the potassium content was higher in the managed region due to structural land management measures than in the unmanaged area, with a significant difference of p=0.0001. The content was also reduced from 5m (higher location) to 5cm (near position) of the structure on the managed region (p=0.0001). The study findings were also consistent with the findings of Carson (1989), who reported that potassium loss was considerably higher in unmanaged farmlands compared to managed farmlands.

4. Conclusion and Recommendation

The study concludes that structural land management is highly effective to improve soil physical and chemical properties that help to improve land productivity. The sand and silt fractions were significantly higher in unmanaged farm fields than managed fields, and showed significant increase when the sampling point far from the soil bund in 5cm to 5m. But, the clay fraction was significantly higher in managed farm field by soil bund than unmanaged and showed significant decrease when the farness increased from 5cm to 5m. Soil moisture, pH, organic carbon, total nitrogen, phosphorus and cation exchange capacity of soil were significantly higher in farm fields managed by soil bund at $p<0.05$. While Bulk density was significantly higher in unmanaged farm field than managed. The effects of structural land management measures were significant in almost all soil physicochemical properties at $P < 0.01$ except for the sand, silt content and bulk density in farm fields. The study findings revealed that soil bund structural land management measure is by far the most effective, and recommended method to mitigate soil erosion, and refining soil physical and chemical properties in the Tutete and Chelbakebele's of Yirgachafe district. Helpfully local community should be aware on the effect and importance of structural land management practices on soil properties that help to boost land productivity. Therefore, governmental and non-governmental stakeholders should work together to strengthen and sustain the implementation process of the structural land management measures. This study is limited to physical land management measures specifically soil bund, farmland, agro-ecology and slope of the area. Further study is recommended based on the limitation.

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