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Full Length Research Paper

Nitrogen use efficiency of tef [Eragrostis tef (Zucc.) Trotter] as affected by nitrogen fertilizer under chickpea-tef rotation at Tahtay Koraro District, North Ethiopia

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Study was carried out to evaluate the supplementary nitrogen requirement of tef to enhance nitrogen use efficiency of tef grown under chickpea-tef rotation cropping. On-farm, experiment was conducted during the 2015 main cropping season at Tahtay Koraro District of the Tigray regional State, Ethiopia on tef after preceding chickpea. The experiment was set in a randomized complete block design with three replications. Seven treatments: Six N levels (0, 11.5, 23, 34.5, 46, and 69 kg N ha^{-1}) under the chickpea-tef rotation and the seventh one negative control (0 kg N ha^{-1}) under the continuous tef cropping were tested. Surface soil samples were collected before tef sowing and after harvesting. They were analyzed for selected soil properties. Clay sized particles dominate the soil of the experimental site and the textural class of the soil is clayey. There was a difference in the bulk density of the same soil between the chickpea-tef and tef-tef sequence. Nitrogen and organic carbon were higher in soil under chickpea-tef cropping sequence than in soil under continuous tef cropping. Application of different N rates under chickpea-tef rotation statistically significantly affected grain (GNU), straw (SNU) and total nitrogen uptake (TNU) (kg ha^{-1}). The highest total tef nitrogen uptake (59 kg N ha^{-1}) was obtained in response to application of 34.5 kg N ha^{-1}. The highest apparent nitrogen recovery (81%), agronomic efficiency (10.48 kg kg^{-1}) and physiological N use efficiency were obtained in response to the lower N rate (11.5 kg N ha^{-1}), 23 kg N ha^{-1} rate and 34.5 kg N ha^{-1} respectively. The highest grain protein content (7.78%) was recorded for grain harvested from plots fertilized with 23 kg N ha^{-1}. Hence, it could be concluded that, under chickpea-tef rotation cropping system some supplementary nitrogen is needed to fulfill the nitrogen requirement and nitrogen use efficiency of tef crop at the study area.

Key words: Chickpea, tef, nitrogen uptake, nitrogen use efficiency, protein content.

INTRODUCTION

Despite its staple importance in the overall national food security of the country (Kebebew et al., 2013), tef [*Eragrostic* tef (Zucc.) *trotter*] productivity is relatively low. Tef productivity and quality in Tigray is habituated by various factors of which environmental, genetics, management, capital, and input conditions are the most

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relevant. In most cases, high tef yield demands an increase in nitrogen application. Nitrogen fertilizer is one of the main inputs for cereals production; as it is often the most limiting nutrient for crop yield in many parts of the world (Giller, 2004).

Many-fold increase in the use of fertilizers nitrogen was detected with the increased agricultural food production worldwide over the past few decades. Therefore, the accommodation of the needs of the escalating world population by developing a highly productive agriculture, whilst at the same time preserving the quality of the environment (Hirel et al., 2007) is believed to be challenging for the next decades. Excessive addition of this nutrient can contribute to the combined effects of denitrification, volatilization and leaching then watercourse pollution (Semenov et al., 2007). Reduction of applied N fertilizer rate to an optimized level can reduce soil nitrate leaching (Power et al., 2000).

Development of a more sustainable agricultural production and cropping system is becoming very important nowadays to improve soil nitrogen; this includes legumes in the cereals cropping system; rotation, inter-cropping, which is the most effective tool for significant reduction of the uses of external mineral N-input and an increase of crops nitrogen uptake and use efficiency (Nevens et al., 2004); it maintains soil structure, increases soil organic matter, increases water use efficiency, reduces soil erosion and pest infestation (Halvorson et al., 2004 and Riedell et al., 2009). Nitrogen use efficiency (NUE) for cereal production including tef is approximately 33% (Raun and Johson, 1999) worldwide.

Research is required to increase crop NUE and profitability to develop sustainable farming systems in response to persistently increasing economic and environmental pressures. According to Sowers et al. (1994), the application of high nitrogen rates may result in poor nitrogen uptake and low NUE due to excessive nitrogen losses. A better insight of NUE of tef is needed to augment sustainability of legume-cereal base rotations. Lopez and Lopez (2001) showed that nitrogen efficiency indices are significantly affected by crop rotation and nitrogen fertilizer rate. Yamoah et al. (1998) concluded that nitrogen efficiency is greater in crop rotation than in monoculture systems.

Crop rotation; legume with cereals has been practiced for long to improve soil fertility and increase productivity of the succeeding non-leguminous crops in Tigray. Fababean, chickpea, and vetch are commonly used in the rotation system in most areas of the region. In the study area, farmers most time rotate chickpea with *tef*. The valuable influence of legume based rotation cropping system is well known in the study area.

Farmers use nitrogen and phosphorus fertilizers for their cereal crops at a rate of 69 and 46 kg ha^{-1}, respectively which is a blanket recommendation. However, after leguminous crops, farmers decide on how much nitrogen fertilizer they have to apply for their subsequent cereal crops based on their experiences. They reduce nitrogen fertilizer to half and even to zero for their succeeding cereal crops. This is because there is a knowledge gap on the significant contribution of preceding legumes to soil nitrogen addition and its effect on nitrogen use efficiency for succeeding t*ef* crop. Hence, this study was carried out to evaluate the nitrogen use efficiency of tef as influenced by supplementary nitrogen fertilizer rates after chickpea.

MATERIALS AND METHODS

Field experiment was conducted during the 2015 cropping season on selected farmers' field at Tahtay Koraro District, northwestern Tigray, northern Ethiopia (1,957 m.a.s.l., 14°03' 48.9'' N and 38°23' 51.9'' E). The area was selected for its long term experience in chickpea-tef rotation cropping system. Soil type of the study area is mainly vertisol (TFEB, 1995) (Figure 1).

The district is categorized under the semi-arid tropical mid highlands (SA_3) belt of Ethiopia where most of the middle altitude crops such as tef *(Eragrostic tef*), fababean (*Vicia faba* L.), and chickpea (*Cicer arietinum* L.) are commonly grown. The area is characterized by uni-modal rainfall pattern and received annual rainfall of 769.71 mm during the experimentation in 2015 cropping season. The average maximum and minimum temperatures were 28.87 and 13.86°C, respectively (Figure 2).

The trial area was sown to tef without any fertilizers application in order to exhaust nutrients built up from previous cropping seasons during the 2013 cropping season. In the following year, 2014, chickpea cv. *Mariye* was sown at a seed rate of 150 kg ha^{-1}. During 2015 cropping season, tef cv. *Quncho* was sown at a seed rate of 10 kg ha^{-1}, with six levels of nitrogen (0, 11.5, 23, 34.5, 46, and 69 kg N ha^{-1}) applied to plots under chickpea-tef rotation and one negative control to plots under *tef-tef* cropping sequence. This negative control was used to see the contribution of chickpea to residual nitrogen. The experiment was arranged in a randomized complete block design (RCBD) replicated three times. Plot size was 4 by 3 m (12 m^2). The spacing between blocks plots and plant rows was 1 m, 0.5 m and 20 cm, respectively.

Most of the local farmers do not use fertilizer later for legumes for successive cereals, but some farmers use nitrogen fertilizer at a rate of 23 kg ha^{-1}. Thus, the nitrogen levels were formulated based on the level that the local farmers use. Nitrogen was applied in split at sowing and the remaining at tillering initiation period for the tef crop to supply nitrogen at different stages and to reduce nitrogen loss. Plots received phosphorus, potassium and sulfur fertilizers at rates 69 kg P_2O_5 ha^{-1}, 80 kg K_2O ha^{-1} and 30 kg S ha^{-1}as; triple super phosphate (TSP), potassium chloride (KCl) and calcium sulphate (gypsum), respectively in basal at planting. All plots were hand-weeded.

Representative soil samples were collected from 21 experimental plots before and after the experimentation in 2015 cropping season, using zigzag sampling method from 0 to 20 cm depth. Accordingly, seven composite samples were made from plots that received the same treatments. The collected composite soil samples were air dried, milled and sieved to pass through a 2 mm sieve except for soil organic carbon (OC) and total N analysis which passed through 0.5 mm sieve (Table 1). Organic matter (OM) was calculated by multiplying organic carbon figure by the conventional "Van Berminelen factor" of 1.724. Samples taken after the chickpea were used to see the contribution of precursor chickpea to soil physico-chemical properties. Later, crop maturity tef was hand harvested from a net plot size of (10.4 m^2), air dried and biomass was recorded and threshed.

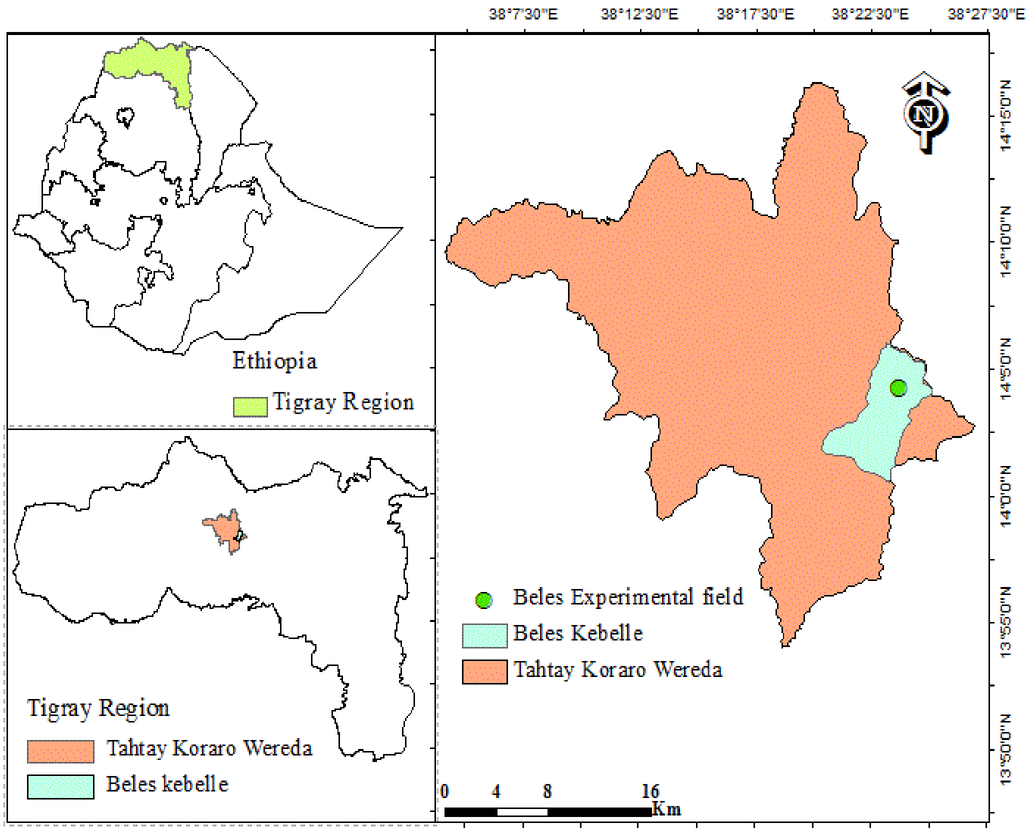

Figure 1. Location map of the study area.

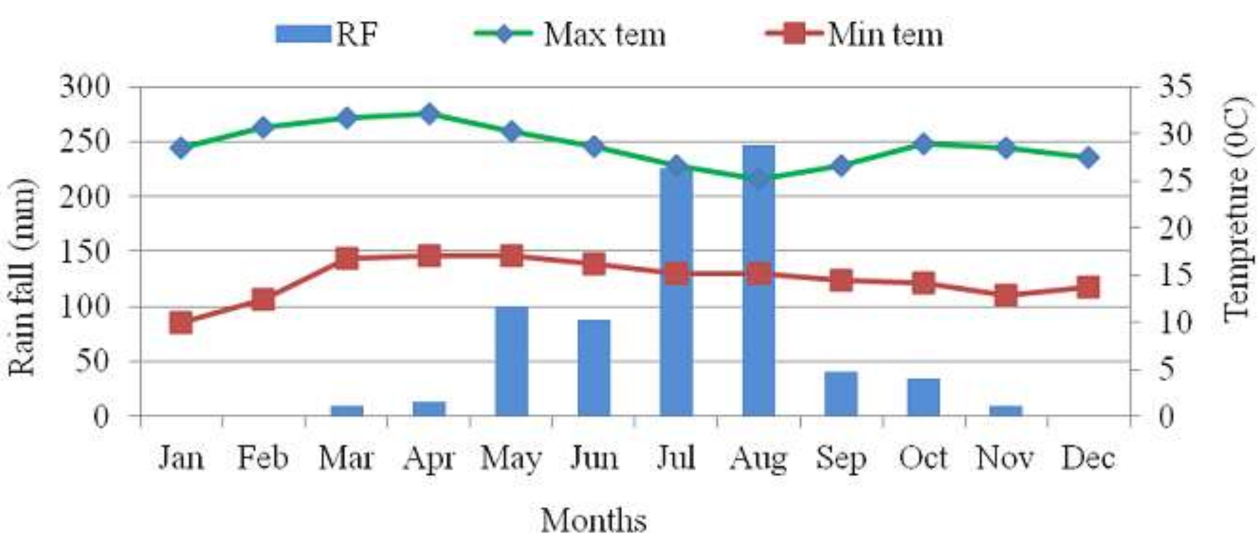

Figure 2. Monthly rain fall, maximum and minimum temperature of the study area for 2015 cropping season (Where; RF= Rain Fall, Max tem= Maximum temperature and Min tem= Minimum temperature).

Following threshing, grain and straw yields were calculated on a hectare basis at 12 and 20% moisture content, respectively. Plant samples were also collected randomly after maturity, from each experimental plot for nitrogen analysis. The plant samples were partitioned into grain and straw and washed with distilled water to clean the samples from contaminants like dust before grinding. The grain and straw samples (after washing) were separately oven dried at 70°C until it retained constant weight for 24 h. After drying, the

Table 1. Soil and plant parameters analyzed and their respective methods.

Parameter	Method of analysis	According to
Particle size	Hydrometer method	Bouyoucos (1962)
pH (1:2.5)	Potentiometric method	Rhoades (1982)
EC (1:2.5)	EC meter	Jakson (1967)
OC	Wet Oxidation method	Walkely and Black (1934)
TN	Kejeldah method	Bremner and Mulvaney (1982)
Avail. P	Olsen method	Olsen et al (1954)
CEC	Ammonium acetate method	FAO (2008)

plant tissue samples were ground and passed through 0.5 mm sieve for analysis of N concentration.

Grain and straw nitrogen contents (%), on a dry matter basis were determined by micro-Kjeldahl digestion procedure as described by Bremner and Mulvaney (1982). Total Nitrogen uptake (kg ha^{-1}) of teff was calculated by multiplying the nitrogen content of the straw and grain by their respective yields (Bowen and Zapata, 1991). Using the procedures described by Fageria and Baligar (2003), apparent N recovery (AR) in cereal biomass, agronomic efficiency (AE) of fertilizer N and physiological N use efficiency were calculated.

Total nitrogen uptake

N uptake of grain or straw (kg ha^{-1}) = Yield of grain or straw (kg ha^{-1}) x N concentration of grain or straw (%) x 10^{-2} (i)

Total N uptake = N uptake of grain + N uptake of straw (ii)

Apparent N recovery (kg kg^{-1})

Apparent N recovery = $(Un - U_0)/n$ ………………………..….. (iii)

Where; Un stand for nutrient uptake at 'n' rate of fertilizer, Uo stands for nutrient uptake at control (no fertilizer) and 'n' stand for amount of fertilizer applied.

Agronomic N use efficiency (kg kg^{-1})

Agronomic N use efficiency = $(Gn - G_0)/n$ ………..……….. (iv)

Where; Gn and Go stand for grain yield fertilized at 'n' rates of fertilizer and grain yield unfertilized, respectively, and 'n' stand for nutrient applied.

Physiological N use efficiency (kg kg^{-1})

Physiological N use efficiency = (Yn - Y0) / (Un - U0) …….. (v)

Where; Yn is the total biological yield (grain plus straw) of the fertilized plot, Yu is the total biological yield in the unfertilized plot, Un is the nutrient accumulation in a fertilized plot, and Uo is the nutrient accumulation in the unfertilized plot.

Grain protein

This was calculated as (AACC, 2000)
% grain protein = % N in grain × 5.7 ……………..…..……… (vi)

RESULTS AND DISCUSSION

Physical properties of the soil

Particle size distributions

Result indicated that particle size distribution is almost similar in both chickpea-tef and tef-tef cropping sequence. As shown in Table 2, clay size particles dominate from the soil particles in the experimental site; hence, the textural class of the soil is clayey.

Bulk density: Even though it is insignificant, the result showed a difference in bulk density among the two cropping sequences. The experimental soil was found to have bulk density of 1.33 and 1.34 g cm^{-3} for chickpea-tef and tef-tef sequence, respectively (Table 2). Since organic matter promotes aggregation and, thus, tends to reduce bulk density, this lower bulk density may be attributed to the effect of the precursor chickpea that contributes organic matter to the soil.

Chemical properties of soils

Soil reaction

The soil reaction (pH) level of the experimental site for both cropping sequences before planting tef and after harvest was almost constant (Table 3). According to Tekalign (1991), soil reaction rating, and soil of the study site is classified under moderately alkaline in reaction. Measurements of EC are used as indication of total quantities of soluble salts in soils. Also based on Marx et al. (1999) rating reported that, soil of the experimental site is categorized under low level of soluble salts and has no salinity problem.

Organic carbon

Results in Table 3 indicate that, organic carbon (OC) was higher in soil under chickpea-tef cropping sequence than in soil under continuous tef cropping. Hence, the preceding chickpea contributed to increased level of OC

Table 2. Physical properties of the soil of the experimental site (0-20 cm).

Cropping sequence	Particle sizes distribution			Textural class	Bulk density (g cm^{-3})
	Sand	Silt	Clay		
Chickpea-tef	16	30	54	Clay	1.33
Tef-Tef	18	29	53	Clay	1.34

Table 3. Selected soil chemical properties of the experimental site before and after tef planting.

Cropping sequence	Time of sampling	pH	EC (mmhos cm^{-1})	OC (%)	TN (%)	Av. P (mg kg^{-1})	Ex. K (ppm)	CEC (cmol(+) kg^{-1})
Chickpea-tef	Before	7.86	0.26	0.94	0.12	5.26	0.54	48.54
	After	7.73	0.23	0.67	0.08	6.39	0.59	50.2
Tef-Tef	Before	7.67	0.28	0.52	0.10	5.10	0.37	46
	After	7.61	0.24	0.60	0.06	5.62	0.66	47.8

Where; pH= power of Hydrogen, EC = Electrical Conductivity, OC= Organic Carbon, OM= Organic Matter, TN= Total Nitrogen, Av.P= Available Phosphorus, Ex.K= Exchangeable Potassium and CEC= Cation Exchange Capacity.

in the soil as compared to the tef-tef mono cropping. After harvesting tef, percent organic carbon in soil under chickpea-tef cropping sequence decreased by 28%, while it increased by 15% under tef-tef cropping sequence compared to that before tef sowing. This shows organic carbon depletion from soil under chickpea-tef cropping sequence.

This depletion could be due to higher soil nitrogen content (Table 3) under chickpea-tef cropping sequence that could be used by microorganisms to multiply their cells and subsequently increase organic matter decomposition.

Total nitrogen

Soil TN content is higher for chickpea-tef cropping sequence than continuous tef cropping before sowing and after harvesting (Table 3). This higher nitrogen concentration in the chickpea-tef rotation might be due to the contribution of previous chickpea to soil N accumulation.

In line with this, chickpea has a role to play in the maintenance of the soil N fertility in the cereal-based cropping systems of the Ethiopian highlands, either directly through the net effect of fixed or more likely through the sparing of soil nitrate (Holford and Crocker, 1997). The soil TN content before tef sowing was higher than that of after harvest for both cropping sequences.

Available phosphorus (Olsen P)

Available phosphorus content of soil was higher for soil under chickpea-tef cropping sequence relative to tef mono cropping system. Therefore, chickpea-tef cropping sequence has potential of improving available soil phosphorus.

Cation exchange capacity (CEC)

Data in Table 3 indicate that, CEC of the soil was very high as per the rating established by Landon (1991). This high CEC might be due to, higher clay content of the soil which contributes to higher CEC. CEC of soil under both cropping sequences was higher after harvesting than before tef sowing.

Residual nitrogen in the soil

Nitrogen accumulated in soil before tef sowing and after tef harvesting was assessed as the average result of plots that received the same treatments. Before sowing tef, higher residual nitrogen was recorded for the chickpea-tef rotation as compared to that of tef-tef sequence. This might be because of, part of the N fixed by the precursor chickpea remains in the soil as root residues or litter fall (Table 4).

Yaacob and Blair (1980) noted that, N content of soil is increased by including legumes in the cropping systems. Hence, legume cultivation increases soil organic N content which conserves N for use by subsequently planted cereal crops. However, after harvesting tef, results revealed depletion of N rather than its accumulation as residual N in the soil. More N was depleted from plots treated with 0 and 69 kg N ha^{-1} under

Table 4. Amounts of nitrogen in soil before and after tef harvesting.

Treatment (kg N ha^{-1})	Soil N before sowing		Soil N after harvesting		Depleted N (kg ha^{-1})
	SN (%)	T + SN (kg ha^{-1})	(%)	(kg ha^{-1})	
0	0.12	3192	0.06	1596	1596
11.5	0.11	2938	0.10	2660	278
23	0.11	2949	0.09	2394	555
34.5	0.10	2695	0.06	1596	1099
46	0.09	2440	0.07	1862	578
69	0.13	3527	0.07	1862	1665
Under continuous tef cropping					
0	0.10	2680	0.06	1596	1084

Where; SN= Soil Nitrogen, T= treatment.

Table 5. Nitrogen uptake of tef as affected by nitrogen fertilizer and previous chickpea.

Nitrogen rates (N kg ha^{-1})		GNU	SNU	TNU
			(kg ha^{-1})	
	0.00	12.72	15.01	27.73
	11.50	13.68	23.89	37.57
	23.00	17.53	31.85	49.38
	34.50	15.41	36.57	51.98
Chickpea-tef sequence	46.00	16.31	40.02	56.33
	69.00	16.24	39.00	55.24
Tef-tef sequence	0.00	11.76	25.69	37.45

Where; GNU= Grain Nitrogen Uptake, SNU= Straw Nitrogen Uptake and TNU= Total Nitrogen Uptake.

chickpea tef cropping sequence followed by plots treated with 0 and 34.5 kg N ha^{-1} under tef-tef and chickpea-tef cropping sequences, respectively.

More depletions of N from plots not treated were expected as plant that used the available N in the soil.

Conversely, more depletion of N from plots treated with higher rates of N could be due to higher biomass production than grain yield (Appendix Table 1). Only higher grain yield was obtained from plots treated with 34.5 kg N ha^{-1}. Therefore, at higher rates more N was used for plant biomass production than grain yield in this study.

Nitrogen uptake of tef

Grain, straw and total N uptake of tef

Tef responded considerably to the precursor chickpea during two year of experiment at the study area. Fertilizer nitrogen application for tef after chickpea positively affected grain (GNU), straw (SNU) and total nitrogen uptake (TNU) (kg ha^{-1}). The result shows that total nitrogen uptake improved with increasing rate of nitrogen and tend to decline at higher rates beyond 46 kg N ha^{-1} (Table 5) in rotation with chickpea. Highest total nitrogen uptake (56.33 kg N ha^{-1}) was recorded for 46 kg N ha^{-1} rate.

In line with this study, Selamyihun et al. (1999) reported that total N uptake increased significantly, concomitant with grain and straw yields, up to the application 30 kg N ha^{-1} rate: TNU values were 43.9, 62.2 and 66.6 kg N ha^{-1} for 0, 30 and 60 kg fertilizer N ha^{-1}, respectively. The total nitrogen uptake has a positive association with that of economic yield. Therefore, the treatment that gave maximum economic yield (23 kg N ha^{-1}) statistically the same with plots received 34.5 kg N $^{ha-1}$ was also highest in total nitrogen uptake. (23 kg N ha^{-1}) was also highest in economic yield statistically the same with plots received 34.5 kg N ha^{-1}.

Nitrogen use efficiency indices

Apparent nitrogen recovery (ANR)

The different rates of nitrogen applied under chickpea-tef rotation cropping influenced by apparent nitrogen recovery of tef. According to the result obtain, ANR was highest (90%) at the lower N rate applied (11.5 kg N ha^{-1})

Table 6. Apparent nitrogen recovery, agronomic and physiologic nitrogen use efficiency of tef.

Treatments (kg N ha^{-1})		ANR (%)	ANUE (kg kg^{-1})	PNUE (kg kg^{-1})
	0.00	0	0	0
	11.50	90	4.78	47.94
	23.00	75	10.48	98.02
	34.50	75	7.62	85.83
Chickpea-tef sequence	46.00	62	4.85	82.92
	69.00	41	2.22	97.68
Tef-tef sequence	0.00	0	0	0.00

Where; ANR= Apparent Nitrogen Recovery, ANUE= Agronomic Nitrogen Use Efficiency and PNUE= Physiological Nitrogen Use Efficiency.

and lowest (41%) at the higher (69 kg N ha^{-1}) N rate applied. This indicates that, as the application of fertilizer nitrogen increases the chance of tef plants to extract the entire applied N to its biomass decreases (Table 6).

In line with this study, Abraha (2013) and Haile et al. (2012) also reported that N uptake efficiency was higher at lower rates of N application but drastically decreased with further increase in the rate of the nutrient for tef and wheat, respectively. This might be due to combination of leaching, fixation and volatilization at higher N rates other than plant uptake.

According to Dobermann (2005), apparent N recovery efficiency of tef at the plot supplemented with higher N (69 kg N ha^{-1}) fell within the common range (30 to 50%) values, whereas the rest of the plots showed the experiment was under well managed system (> 50%). Selamyihun et al. (1999) also reported that; mean apparent recovery (ANR) of fertilizer N in above-ground biomass of tef was 61.1 and 14.5% across two seasons for 0 to 30 and 30 to 60 kg N ha^{-1} intervals, respectively for tef.

Agronomic (ANUE) and physiological nitrogen use efficiency (PNUE)

Both ANUE and PNUE of tef were significantly affected by the different nitrogen rates applied under chickpea-tef rotational cropping. Teff ANUE exhibited decreasing mean values with increasing levels of nitrogen (from 10.48 to 2.22 kg grain per kg applied N) which means under lower N rates, dry matter partitioned to the grain per unit of total plant N was higher compared with the higher N rates (Table 6). This indicated that at low level of nitrogen the primary factor limiting crop growth and final yield is nitrogen and at higher N supply incremental yield gains become smaller because yield determining factors other than N become more limiting as the maximum yield potential is approached (Dobermann, 2005). According to this author, the higher agronomic efficiency (10.48 kg kg^{-1}) of N applied to tef at this particular study falls within the common range (10 to 30 kg kg^{-1}). The N requirement of tef after precursor chickpea targeting on an economic yield was 23 kg ha^{-1} as compared with the other rates.

Physiological N use efficiency of tef under different N application rate ranged from 47 to 98 kg kg^{-1} N. Highest PNUE of nitrogen was obtained from plots supplemented with 23 kg N ha^{-1} (Table 6). Except for plots that were treated with 11.5 kg N ha^{-1}, physiological N efficiency was whether beyond the common range (> 60 kg kg^{-1}) which might contribute to the fact that the experiment was under well managed system or the soil had low nitrogen supply or else there was higher N loss through leaching, volatilization, and so on (Dobermann, 2005).

Grain protein content

Grain protein content of tef was affected by the N rates applied at the study area. The highest and lowest grain protein contents were recorded for grain harvested from plots fertilized with 23 kg N ha^{-1} (7.78%) in the form of urea and 0 kg N ha^{-1} (on both rotation systems) (6.95%), respectively (Figure 3). In general grain protein content showed nearly increasing trend with nitrogen rates at the study area.

Thus results are in line with Halvorson et al. (2004) and Bereket et al. (2014) who reported that grain protein content of cereals increased with nitrogen rates. Grain protein content under chickpea-tef rotation was greater than that of tef-tef rotation at the study area. This may be due to the effect of legumes on residual N.

Conclusion

Crop rotation especially, legume with cereals has been practiced for long to improve soil fertility for the succeeding non-leguminous crops in Tigray. In the study area, farmers most of the time rotate chickpea with tef in order to improve fertility of their soil, nutrient use efficiency of their crops and increase tef productivity. Although the beneficial effects of rotating leguminous crops with

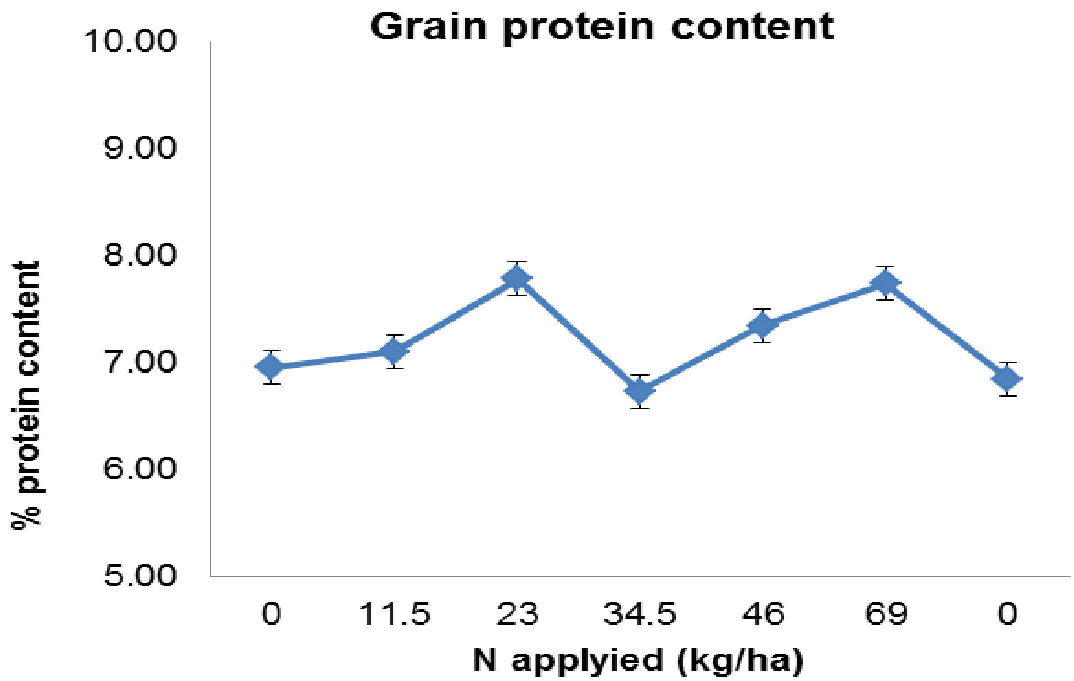

Figure 3. Grain protein content as affected by the different N rates at the study area.

cereals were well known in the study area, there was an information gap on contribution of preceding legumes on the significant nitrogen addition to the soil and its effect on nitrogen use efficiency for succeeding cereal crops (tef). Accordingly, study was carried out to determine the nitrogen use efficiency of teff as influenced by supplementary nitrogen fertilizer rates after chickpea.

Application of different N rates in the chickpea-teff rotation significantly affected crop nitrogen uptake and use efficiency indices. The highest total nitrogen uptake was recorded from the 46 kg N ha^{-1} rate. Apparent nitrogen recovery, agronomic and physiological nitrogen use efficiencies were also significantly influenced by different nitrogen levels applied. Apparent nitrogen recovery of N applied to tef was decreased with increased rates of nitrogen in the chickpea-tef rotation. Maximum agronomic efficiency (10.48 kg kg^{-1}) of N applied to tef was obtained from the 23 kg N ha^{-1} rate and decreased beyond this rate; indicating reducing biological response to increased N rates exceeding 23 kg ha^{-1}. Highest physiological efficiency of nitrogen was also obtained from plots supplemented with 34.5 kg N ha^{-1}.

Therefore, it could be concluded that, under chickpea-teff rotation cropping system some amount of supplementary nitrogen input is needed to fulfill the nitrogen requirement and nitrogen use efficiency of tef crop at the study area. Legume-cereal rotational cropping system is important to reduce the input of inorganic nitrogen fertilizers, improve crops nitrogen use efficiency, reduce environmental pollution and for the soil to sustainably produce yield.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Appendix Table 1. Grain yield of tef as influenced by N rate after precursor chickpea, 2015 main cropping season.

Cropping sequences	Treatment (N kg ha^{-1})	GY (kg ha^{-1})
Chickpea-tef Sequence	0.00	1043^{cd}
	11.5	1098^{c}
	23.0	1284^{a}
	34.5	1306^{a}
	46.0	1266^{ab}
	69.0	1196^{b}
Tef-tef sequence	0.00	980^{d}
Mean		117
LSD (P≤0.05)		87
CV (%)		4.2

Where; GY= Grain Yield, LSD= Least significant difference and CV= Coefficient of Variance; Variable means followed by the same letters are not significantly different (P ≤ 0.05) according to LSD Tests.

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Technical viability of physical soil and water conservation structures implemented in Lake Hawassa watershed, southern Ethiopia.

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Physical soil and water conservation measures with ultimate intention of reducing sever soil erosion and its associated impact had been implemented for the last four decades in southern Ethiopia. Yet, so far the technical viability of the implemented structures weren't studied. Therefore, the objective of this study was to evaluate the technical viability of the implemented physical soil and water conservation measures and its management, maintenance and appropriateness in communal and private lands of the upper catchments of Lake Hawassa watershed. The data was collected by field observation and direct measurement of the implemented structures. Moreover, focused group discussion and key informant interview was done. Descriptive statistics was used for data analysis. The results were compared with standards. The collected data were presented in Table and Figures. The study result showed that Level soil bund and Check dam were implemented in communal land by public participation, while Level soil bunds and Fanya- juu were found in private land. The implemented structures were appropriate for the catchment, while the layouts of most implemented structures were not as the standard. The regular maintenance and management practices were also minimal. As the result, technically deficient SWC measures were found as cause of soil erosion and witnessed that construction of SWC structure in field is not an end means by itself for effective controlling of soil erosion. To be effective the implemented SWC structures has to be appropriate for the area and technically be sound. Regular maintenance and management of the structure after implementation is also vital to achieve its very inception objective.

Key words: Check dam, Level Fanya- juu, soil bund, standards.

INTRODUCTION

Soil properties which affect the plant growth are a complex combination of physical, chemical and biological processes (Coleman et al., 1983; Bargali et al., 1993; Joshi et al., 1997). Soil degradation in last few decades have been increased tremendously and adversely affected the productivity at global scale (Bargali et al., 2018; Padalia et al., 2018). It is prevalent at a tragic rate in Ethiopia. Land degradation, comprising degradation of

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ABBREVIATIONS: SNNPR, Southern Nations and Nationalities Regional State; **SWC,** Soil and Water Conservation natural vegetation, soil erosion, loss of soil fertility and moisture stress is a well-known problem in Ethiopia (Herweg and Stillhardt, 1999). It was estimated that about 1.5 billion tons of soil which has the monetary value of US$1 to 2 billion per year is being eroded every year. The rate of erosion in highlands of the country is extreme and reaches up to 300 tons per hectare annually (FAO, 1984; Hurni, 1988; Hawando, 1997). Out of 60 million hectares of estimated agriculturally productive land, 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares reached at the point which is irreversible (FAO, 1984). Land degradation, particularly by water erosion, is a major threat to food security, environmental sustainability and prospects for rural development in Ethiopia (Bishaw, 2001).

To minimize the negative impacts of soil erosion, both local communities and government has been using their tremendous efforts towards soil and water conservation (Wolancho, 2015). A traditional soil conservation practices and agronomic measures had been practiced in various parts of the country including terracing of Konso people (Lundgren, 1993; Osman and Severborn, 2001). The government's efforts towards soil conservation were started during the 1970’s (Hurni, 1986; Desta et al., 2005). Since then, a huge amount of money has been invested in an attempt to introduce soil and water conservation measures particularly in the areas where the problem of soil erosion is threatening and food deficit is widespread (Desta et al., 2005). However, due its large scale planning units which range 30 to 40 thousands of hectares and absence of local community participation the projects were ended with unsatisfactory results during the first two decades of its commencement (Desta et al., 2005; Habtamu, 2011).

In the early 1980’s, the Ethiopia government with the aid from international government or non-government organization had actively involved in soil and water conservation programs. A package of soil and water conservation measure was developed through constructing terraces, bunds, tree planting and closure of grazing areas (Elias, 2005).During this period, from 1976 up to 1988, food for work programs founded the construction of 800,000 km of soil and stone bunds on cultivated land, 600,000 km of hill side terraces were built, and 80, 000 hectares were closured for regeneration. As the government realized the problem of land degradation, it took policy action. In this regard a forestation and wildlife conservation and development policy was declared in 1980. From 1991 to 2001, following the policy the government initiated various studies and capacity building program and massive soil and water conservation interventions that focused on the cultivated lands. The capacity building program involved training of professionals at the national level and farmers on the local. In this regard, soil and water conservation was included in the university curriculum and the mandate to train farmers was given to the ministry of agriculture and rural development (Bekele and Holder, 1999).

Starting from 2005, watershed management projects focuses on the wise use of natural resources such as land, water and vegetation in given watershed to obtain an optimum level of production with the minimum level of ecological degradation (Desta et al., 2005). To achieve this end, since 2010, the movement on watershed management campaign is going on throughout the country (Wolancho, 2015; Meshesha and Birhanu, 2015). Besides to the efforts made by several NGOs, the campaign on soil and water conservation program which was initiated by FDRE government for the last one a decade has offered a positive contribution in watershed development and management for the country (Meshesha and Birhanu, 2015). On the other hands, stakeholders are debating about the negative impacts of SWC structures on the farm land.This stakeholders argue that the structures were aggravating erosion, rather than meeting its very objective. It is known that the success of implemented soil and water conservation structure is the function of several factors including environmental, economic, social, institutional and technical aspects. Among many other factors, to be effective the implemented structure should be technically sound. The technical viability of soil and water conservation is useful to determine whether the structures are working successfully or not. Therefore, the ultimate purpose of this study is to evaluate the technical viability of physical soil and water conservation structures implemented in the upper catchment of Lake Hawassa watershed. It is hypothesized that the SWC structures implemented in the upper catchments of Lake Hawassa watershed fit the standards and appropriate for the area. In this catchment, physical SWC structures were implemented both on communal and private lands.

MATERIALS AND METHODS

Description of the study area

The study area, Lake Hawassa watershed, is located within the central rift valley of Ethiopia and it has 1455 Km^2 area (Kebede et al., 2014). The upper catchment of Lake Hawassa watershed is partially found in central rift valley region. The Catchment has is geographically situated between 38°37'E to 38°42'E and 7°02'N to 7°07'N. It covers an area with a wide altitudinal range of 1680 to 2940 m above sea level. The mean annual rainfall of the catchment is 1306.78 mm and bimodal rainfall pattern (Kebede et al., 2014).

Methodology

At the beginning, reconnaissance survey was implemented to select representative areas of the upper lake Hawassa watershed, through the help of the developmental agent and local elders found in the study area. Accordingly, two potential communal and private lands with different soil and water conservation physical structures

Table 1. Standard values for physical soil and water structure layouts.

Layout	Level Fanya-juu Slope <15%	Level soil bund Slope <15%	Gabion check dam Slope >15%
Length*	10	10	10
Top width*	0.5	0.5	0.5
Bottom width*	0.5	0.5	0.5
Depth*	0.5	0.5	0.5
Embankment height*	0.5	0.5	0.5
Embankment top width*	0.3	0.3	0.3
Embankment bottom width*	1.6	1.6	1.6
Tie ridge*	0.5	0.5	0.5
Berm length*	0.25	0.25	0.25
Vertical interval*	1	1.5	1.5
Alignment (degree)	0	0	0

* indicates the units on measurement is in Meter
Source: Hurni (1986) and Desta et al. (2005).

Figure 1. Soil and water conservation structure under construction.
Source: Yericho Berhanu.

were selected purposively and a total of 80 hectares of land, 40 from private and 40 from public were delineated as an experimental unit. Systematic sampling techniques were used to measures the layouts of the structure. The data was collected through measuring the layouts of already implemented physical SWC structures in the area. Based on this, total of 172 physical SWC structure layouts were measured. The layout measurement was done on the implemented structures length, depth, top width, bottom width, embankment height, embankment top width, embankment bottom width, length of tie ridge, berm length, vertical interval and alignment were measured. Moreover, Focused group discussion and key informants interview was done. The appropriates of implemented SWC structures was determined through considering the guidelines provided by Hurni (1986) and Lakew et al. (2005). Moreover, the expert's judgment (appropriate or not) was also taken in to account. The observed layouts of implemented structures were compared with the standards stated in Tabe 1 through using descriptive statistics and t-tests with SPSS 20. Moreover, frequency analysis was conducted for the appropriateness, management and maintenances of the implemented physical SWC structures.

RESULTS AND DISCUSSIONS

Physical soil and water conservation structures implemented in the study area.

Several physical conservation measures with the purpose of reducing surface runoff thereby increasing infiltration were implemented through public participation in the study area (Figure1).

Table 2. Physical SWC structures Implemented in the Upper Lake Hawassa watershed.

Types of structure	Land ownership					
	Private		Public		Private and Public	
	Frequency	%	Frequency	%	Frequency	%
Level soil bund	60	61.9	60	80	120	69.8
Level fanya-juu	37	38.1	0	0	37	21.5
Gabion check dam	0	0	15	20	15	8.7
Total (n)	97	100	75	100	172	100

Table 3. Observed responses on approporateness, management and maintenance of implemented SWC structures in Hawssa wateshed.

Ownership	Physical SWC structure	Measured parameter	Response	
			Yes (%)	No (%)
Private	Level soil bund	Appropriateness	100	0
		Management	20.34	79.66
		Maintenance	20.34	79.66
	Fanya-Juu	Appropriateness	100	0
		Management	21.62	78.38
		Maintenance	21.62	78.38
Communal	Level soil bund	Appropriateness	100	0
		Management	13.3	86.7
		Maintenance	96.7	3.3
	Gabion Check dam	Appropriateness	96.7	3.3
		Management	93.3	6.7
		Maintenance	0	100

Level soil bund and Level Fanya-juu were constructed in the middle and lower parts of the watershed, while Gabion check dam constructed in the gullies of the upper hillsides catchment of the watershed.

The great majority of implemented structures were Level soil bund followed by Level fanya juu and Gabion check dam (Table 2). Level Fanya juu were implemented only in private land where as Gabion check dam is in public land. This result has similar indication with the previous study of Meshesha and Birhanu (2015) in which the aforementioned physical SWC structures were commonly used in the south western parts of Ethiopia. Similar study criticized the diversity SWC in Ethiopia in general and southern Ethiopia in particularly poor. Surprisingly the SNNP region has diverse agro-climatic condition, while it is known that the types of SWC structure implemented in the region was determined and fixed from the center without considering the local agro-ecology and climatic condition. Similar study in south western Ethiopia assures that no one structure is recommended for the entire syndrome in the region, while it has to be condition/site specific.

Appropriateness, management and maintenance of implemented stuctures in the catchment

The result indicated in Table 3 shows the percent of different physical soil and water conservation according to their management, maintenance and appropriateness in the study area.

The result presented in Table 3 shows that considering the local agro-ecology and shallow soil depth stated in Hurni (1986) and Desta et al. (2005), those structures constructed in the area (both in private and public land) were appropriate for the catchment. On the other hands management and maintenance of the implemented structure in the private land is very minimal (Table 3, Figure 2).

This result is in line with findings of Wolancho (2015), in which it he found that lack of regular maintenance is the challenge for campaign works of SWC in southern Ethiopia. In the contrast with private ownership, Management of the structure at public land is very high. This result, contradict with findings of Wolancho (2015). The Key informants stated that because of annual

Figure 2. Weak management and maintenance practice (Cattle heard over and destroying the structure).

national campaign program, the structures in the public land were subjected for regular maintenance via public participation. In opposite, with this, the responsibility of maintaining structures at private land were the mandate of the owner and they were less interested for its maintenance.

Fitness of the layout of implemented structures with standards in communal and private lands in the study area.

The comparison result of the implemented physical SWC structures layout with its test values shows that there were significant differences between the soil conservation dimensions (measured variables) with its design standards (Table 4). All measured parameters, except top embankment width, in the private land were not as the standard. Similarly, in communal land there is a significant difference between the observed result and the standards in most parameters. Except few dimensions, the majority of physical SWC structures both at private and public land were not constructed according to the standard. This indicates that the implemented physical SWC structures were not technically viable.

The result presented in Table 4 shows that the length of all physical soil and water conservation structures, were significantly less than the standards. Similarly, the majority of layouts have negative mean difference and the variation was statistically significant (Table 4). Key informants mentioned that labor cost and lack interest to construct structure in their farm land were the main reason for poor construction of the structures. Similarly, focused group discussion result shows that farmers were forced to construct physical SWC structures both at public and private land, and conclude that the lack of agreement and poor interest were the reason for the structure layouts to fail to meet its design standard. The positive mean difference of vertical interval presented in Table 4 also verify that the structures are constructed far apart beyond the standard, and it indicates that less number of structures are designed to construct at a given parcel of land. This could be probably to save labor cost or lack of understanding about the importance of soil and water conservation structures. According to Meshesha and Birhanu (2015), lack of skill and interest were two main reasons for the constructed structure to fail to meets the standard. Moreover, both key informant interview and focused group discussion also support this finding. One of the key informant stated as follows: "*We are forced to construct the structure, both in our own land and public land, without our interest for the sake of Local Government interest''.* Hence, it is understood that awareness creation and reaching a consensus before commissioning the structure is important for effective intervention.

Conclusion

Physical soil and water conservation structures had been implemented in Ethiopia for last five decades through public participation. The intervention was targeted to reduce severe soil erosion from farm land and associated ill effects land degradation. Moreover, it was focused to maintain soil fertility and improve agricultural productivity. To this end, a lots of effort has been done to conserve soil at private and communal lands, while the success has found to been less comparable with the effort done so far. In spite of having its large area coverage, the contribution/effects of the intervention were criticized by citizens. Most stakeholders argue that implemented structures were the source of severe soil erosion, rather than achieving its initial intentional objective. Moreover,

Table 4. Comparison of physical SWC layouts with standards under both land ownership categories.

Land Ownership	Types of SWC structure	Variable	n	DF	Mean	MD	Test value	t-cal	P-value
Private	Level soil bund	Length	60	59	9.44	-0.56	10	-5.68	0.001
		Top width	60	59	0.46	-0.04	0.5	-3.656	0.001
		Bottom Width	60	59	0.46	-0.04	0.5	-3.656	0.001
		Depth	60	59	0.4	-0.1	0.5	-7.364	0.001
		Embankment height	60	59	0.33	-0.17	0.5	-7.157	0.001
		Length of tie ridge	60	59	0.41	-0.09	0.5	-6.276	0.001
		Embankment top width	60	59	0.32	+0.02	0.3	1.57	NS
		Embankment bottom width	60	59	0.8	-0.8	1.6	-39.88	0.001
		Berm length	60	59	0.37	-0.63	1	-33.89	0.001
		Slope	60	59	9%	-	-	<15%	-
		Soil depth	60	59	0.9	-	-	-	-
		Vertical interval	60	59	1.91	+0.41	1.5	7.65	0.001
	Fanya-Juu	Length	37	36	9.42	-0.58	10	-4.49	0.001
		Top width	37	36	0.45	-0.05	0.5	-2.754	0.009
		Bottom Width	37	36	0.45	-0.05	0.5	-2.754	0.009
		Depth	37	36	0.41	-0.1	0.5	-5.491	0.001
		Embankment height	37	36	0.32	-0.18	0.5	-5.728	0.001
		Length of tie ridge	37	36	0.42	-0.08	0.5	-4.803	0.001
		Embankment top width	37	36	0.33	0.03	0.3	1.43	NS
		Embankment bottom width	37	36	0.81	-0.79	1.6	-30.11	0.001
		Berm length	37	36	0.38	-0.62	1	-25.77	0.001
		Slope	37	36	9%	-	-	<15%	NS
		Soil depth	37	36	0.9	-	-	-	-
		Vertical interval	37	36	1.86	+0.36	1.5	5.3	0.001
Communal	Level soil bund	Length	60	59	7.66	-2.34	10	-7.41	0.001
		Top width	60	59	0.69	+0.19	0.5	10.45	0.007
		Bottom Width	60	59	0.54	+0.04	0.5	2.79	0.001
		Depth	60	59	0.42	-0.09	0.5	-8.08	0.001
		Embankment height	60	59	0.13	-0.37	0.5	-27.89	0.001
		Length of tie ridge	60	59	0.73	+0.23	0.5	2.731	0.008
		Embankment top width	60	59	0.72	+0.42	0.3	6.42	0.001
		Embankment bottom width	60	59	0.91	-0.7	1.6	-9.55	0.001
		Berm length	60	59	0.12	-0.88	1	-53.21	0.001
		Vertical interval	60	59	1.05	-0.45	1.5	-8.9	0.001
	Gabion Check dam	Length	15	14	7.87	-2.13	10	-2.61	0.021
		Top width	15	14	0.56	+0.06	0.5	1.67	NS
		Bottom Width	15	14	0.56	+0.06	0.5	1.67	NS
		Depth	15	14	0.43	-0.07	0.5	-3.56	0.003
		Embankment height	15	14	-	-	0.5	-	-
		Length of tie ridge	15	14	0.11	-0.39	-	-4.11	0.001
		Embankment top width	15	14	-	-	-	-	-
		Embankment bottom width	15	14	-	-	-	-	-
		Berm length	15	14	-	-	1	-	-
		Vertical interval	15	14	1.57	+0.07	1.5	2.22	0.044

Note: (MD is Mean Difference, NS is not significant) this study found that the layout of the implemented structures were not as the standards and fail to fit the design requirements. The practice of regular maintenance and management were also minimal. Due to this reason, until recent soil erosion significantly affects the agricultural sector and threat to the economic development of Ethiopia. Hence, it was assured that simply constructing physical soil and water conservation structure on farm land is not an end means by itself to conserve soil and water, while it has to be as the standard and regular maintenance and management has to be in the place. Otherwise, the end result is beyond the expected.

RECOMMENDATION

Based on the findings of this study, the following recommendations are forwarded:

It is important to enhance farmers' awareness on the importance of soil and water conservation structures since most farmers belief that implementation of structure is minimizing their land area for cultivation.

Capacity building for development agents is also important since poor design alignment of implemented structures were associated with the skills gaps.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This research was done through considering professional ethics and authors are responsibility for any competing interest for participation.

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CONFLICT OF INTERESTS

The author has not declared any conflict of interest.

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