On-farm Quantification and Demonstration of the Extent of Soil Erosion and Nutrient Loss from Slope Farmland Under Millet Production in Kafa Zone, Ethiopia

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Abstract
The study was conducted in Gimbo woreda, kafa zone on soil erosion extent and its risk. The survey result on soil loss in area showed that more than 70% soil erosion occurs on the first month after finger millet sowing. 22x2m runoff plots were laid on six farmers field on which finger millet was sown. The trial farmers were selected based on slope category of farmlands (three farmers with above 10-15% and other three farmers above 16-20%) using FRG (Farmers Research Group) approach with the support of JICA FRG project in 2013. After conducting the erosion measurement during millet production, soil loss was observed to be 61ton/ ha/yr under untreated plot (free plot), 53t/ha under farmer practice and 21t/ha under introduced erosion control. The mean of soil loss under three different treatments over three farmers in slope above 10-15% was 21t/ha. Similarly, the mean of soil loss under three different treatments over three farmers in slope range above 16-20% was 45t/ha resulting to 2.2mm soil layer lost per year under millet production. The soil loss from any land under millet production varied from that of introduced type of soil conservation and farmer practice of soil conservation methods by 40 and 32t/ha respectively. This shows that during millet production on slope land above 16-20%, areas treated by farmer practice and those untreated by any conservation practice exceeded that of introduced soil conservation practice by 150% and 190% respectively indicating that, applying their practice of soil erosion control, farmers could save at least 8t/ha soil from slope land and 4t/ha soil from less slope land during millet production. According to LSD at p=0.05 the soil loss from any land under millet production will vary from that of land with erosion control and farmer practice method of control by 15 and 4t/ha respectively. Areas treated by farmer practice and those untreated will exceed that of introduced soil conservation area by 40% and 60% respectively. The result of study on economic analysis showed that a farmer with such soil erosion in the area will invest 30kg N (65kg Urea) more than blanket recommendation on his land to maintain fertility of his land. It will be 142% cost of fertilizer relative to normal application rate. Farmers during discussion rose possible causes of soil loss in the area were, frequency of tillage during millet production (4-5tmes); Millet is sparsely planted and open throughout the production times and this situation aggravates erosion; Compaction of soil (trampling by animals) during planting; Cultivation of high slope (>15%) farm land for millet and the high and erosive rainfall during the planting season (Jun/July). To solve the problems, millet production should be done with proper SWC works; Slopes above 15% should be treated with 5-6m Contour interval for SWC activity; During watershed development planning, special attention should be given for millet producers in order to reduce soil erosion; Use of strip cropping with width of the strip for a crop (millet or other) not more than 10m and farmers need to be organized for further agricultural experiment through FRG principle as it empowers them to solve their own agricultural productivity problem.
Keywords: Soil loss, Soil erosion, FRG, runoff plots, slope range, millet production

1. Introduction

Soil erosion has been occurring for millions of years. However, accelerated erosion is a much more recent phenomenon. It is the most widespread form of soil degradation. The land area globally affected by erosion is 1094 million ha by water erosion, of which 751 million ha severely affected (Lal, 2003) and loss of potential productivity due to soil erosion worldwide is estimated to be equivalent to some 20 million tons of grain per year (UNEP, 1999).. Soil erosion varies depending on the factors such as crop type or land use, slope, tillage frequency, deforestation and farming system. It is estimated that about 1500 million ton of soil was lost from the highlands of Ethiopia every year, about 50% of the rural population were affected to some degree, and 1–2% of the country's agricultural production was lost (Hurni 1998). The rate of soil loss in Ethiopia was put in severity levels as, very high (>100 t/ha/yr); high (50-100 t/ha/yr); moderate (10-50 t/ha/yr); low (1-10 t/ha/yr) and no erosion (<1 t/ha/yr) (Hurni, 1983). The national average soil loss from cultivated land in Ethiopia was 42t/ha/yr and tolerable soil loss below which soil erosion can not affect productivity was 18t/ha/yr (Hurni, 1983; 1988). However, the variability of erosion exists in the country as 150-200t/ha/yr in Sidama area; 16-50t/ha/yr in Amhara Region (FAO 1986፣ Abegaz, 1995). According to FAO (1986), average soil erosion in SNNPR state was 130t/ha/yr. However, different authors did not conducted soil erosion assessment around southwestern part in detail. Their reason was general assumption that southwest is not depleted with respect to its forest resource. However since there area farmers whose livelihood depend on cash crop production exist there should be expectation of soil erosion and its controlling mechanism. The information on the erosion risk could have great impact on watershed development planning as well as for policy makers.

Erosion is greatly influenced by the extent to which the soil is protected from the energy of the rainfall or surface runoff by the vegetative cover. Many studies have shown that the relationship is non-linear, with a substantial reduction of erosion being caused by relatively small density of cover. For the direct measurement of cover in the field, many methods have been suggested such as aerial photography, runoff plots and various methods to measure the effect of a crop canopy for reduction of soil loss (Stocking, 1988). The principle behind the erosion plots was that it is the better way to compare soil loss on a yearly basis or season basis and show the farmers the real problem related to productivity. Similarly it is important to compare the quantity of soil loss from areas under conservation practices to traditional farming practice and a reference, bare plot. Sustainable use of natural resources requires coordination of conservation efforts between a diverse group of individuals and agencies that view and manage the landscape at different scales, from field level by a farmer, to the entire watersheds at country level (Sheng, 1982).

Under the humid tropics, cultivated slopes of 30 % and the like could lose soils at 100-200 t/ha/year" without practising proper conservation measures (Veloz& Logan; 1988). The actual rates vary according to crops, tillage, soils, and local rainfall patterns and intensities. However, to reduce soil erosion to an acceptable level, therefore, is a much greater challenge to the conservationists under this kind of environment than others (Veloz& Logan; 1988). Past experiences show that, both conservation structures and agronomic conservation measures are needed to control soil detachment and transportation, as well as to safeguard runoff which is inevitable in humid tropics. The right combination of structures and agronomic measures are dependent on local research. The result from runoff plots in Jamaica and Thailand, hillside ditches (the improved type) combined with agronomic measures could reduce erosion by 80%, yet their cost was about 1/5 the cost of bench terraces which may reduce additional 10% of erosion (Sheng, 1990). In spite of obvious high erosion rate in the study area there is limitation of document which can enforce policy makers to plan against degradation.

1.1. Justification of the study

Due to the long range impact of soil erosion on yield of crops, farmers are not willing to construct conservation structures on slope lands for reduction of soil loss but they facilitate cultivation of the slope lands for crop production to feed their family and for income. Among the crops millet production was very common in the study area. Farmers did not value the effect of erosion during cropping season of the crop. The importance of the study has significant response for direct value of soil, environment, society (reduced pollution of rivers, reduced sediment in canals and roads), reduction of fertilizer by erosion all resulting high economic benefit to farmers and other beneficiaries as a whole. Although soil eroded from farmland during millet production sometimes even obstruct the main roads, due to deep and fertile nature of lowland soil of the area, farmers perceive that soil is surplus and has no significant change of depth at the moment. Creating awareness about the impact of erosion on the production and productivity should therefore be crucial.

As a result, creating awareness needs the selection of key farmers and training them on the problem of soil erosion with practical works on the field plots. For this situation FTC is very important and practically applicable. Therefore, this demonstrative research was performed at FTC level and it is expected that farmers practicing cultivation without conservation structure visualized and understood the great impact of soil loss from land and as a result they agreed to implement proper soil and water conservation measures on sloppy lands before cultivation. Therefore, the study was aimed to achieve the following objectives; (1) To evaluate the effect of conservation measures in millet production (2) To know the extent of soil erosion that is taking place under millet production (3)To determine the nutrient loss due to soil erosion under millet production (4)To estimate the economic value of nutrient loss due to erosion

2. Materials and Methods

2.1. Description of the study area

2.1.1. Location and Topography

The study was conducted in Shomaba Kichib Kebele, Gimbo woreda which was located at, Kaffa zone, Southern Nations Nationalities and People's Region (SNNPR). It is found within the southwestern plateau of Ethiopia and 450km and 725km far from Addis Ababa and Hawassa respectively. The area lies within 07°00'- 7°25'N Latitude and 35°55'-36°37'E Longitude. The altitude of the study area ranges from 1600 to 1800 m.a.s.l. The topography is characterized by slopping and rugged areas with very little plain land having sandy clay loam (Matheos, 2001).

2.1.2. Climate

The area experiences one long rainy season, lasting from March /April to October. The mean annual rainfall ranges from 1710 mm to 1892mm. Over 85% of the total annual rainfall, with mean monthly values in the range of 125-250mm occurs in the 8 months long rainy season. The mean temperature ranges from 18.1^{0}C to 19.4^{0}C (Matheos, 2001).

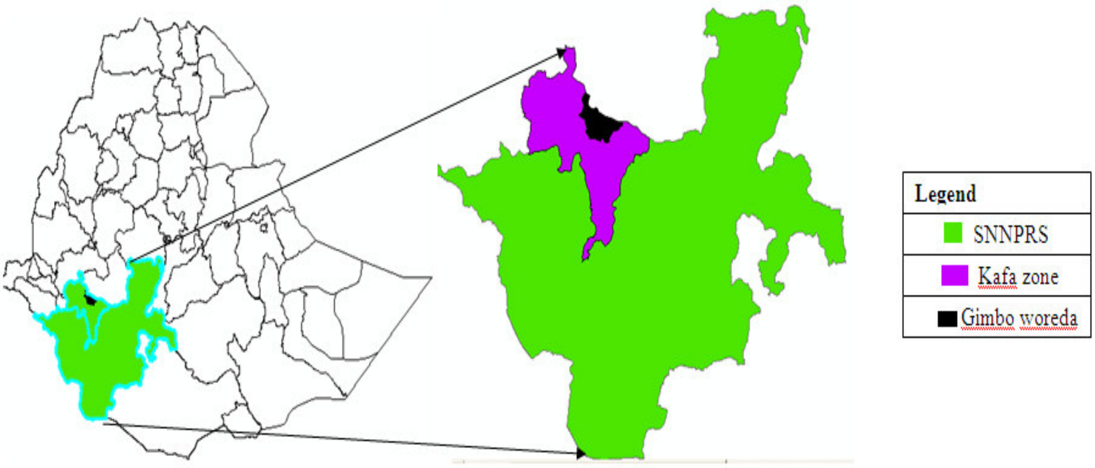

Figure 2: Map of study area

2.2. Method of site and farmer selection

First, seven representative millet producing villages were selected from Shomba kichib and Shomba Sheka kebeles to conduct the erosion research participating selected FRG (Farmer Research Group) with members of 33 farmers (24 male and 9 female).

Three farmers host three treatments under slope category 10-15% and other three farmers host three treatments under slope category 16-20%.

2.3. Research design

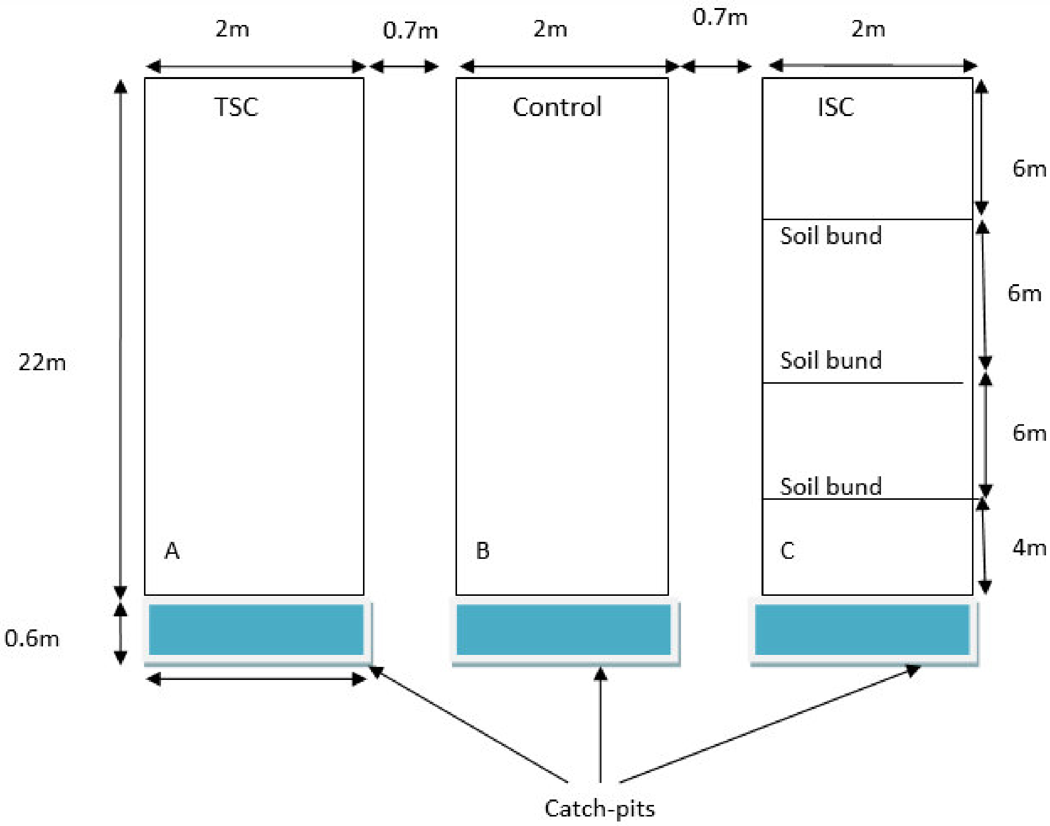

Figure 2: The layout of runoff plots which are closed at top, right and left sides for both slope category (above 10-15% and above 16-20%)

2.4. Installation of runoff plots

Runoff plots for erosion measurement on farmer's land around FTC were installed at cultivated lands of millet production which was expected to aggravate erosion if there is no conservation structure. The site was selected based on the feasibility of setting up of all the erosion plots at one farmer's field and its representativeness of the pilot site.

The three plots (without soil bund, with soil bund and with traditional conservation) (22m x 2m each on the same slope) were bounded by iron sheets (30cm wide) round the plots. At the bottom of the plot a catch-pit was made of 2m length, 0.6m in depth and 0.6m wide.

The catch-pits were covered with a plastic that is intended to collect the eroded soil particles. Small holes were made to drain collected water from the catch-pits. Between the plots an area of at least 0.7m wide was kept to facilitate easy access to the plots.

2.5 Treatments and their arrangement

1. Run off plot with Millet on slope range of 10-15%
2. Run off plot with millet + [1]traditional conservation structure (TCS)+ slope range of 10-5%
3. Run off plot with millet + [2]introduced conservation structure (ICS) + slope range of 10-15%
4. Run off plot with Millet on slope range of 16-20%
5. Run off plot with millet + [1]traditional conservation structure (TCS) +slope range of 16-20%
6. Run off plot with millet + [2]introduced conservation structure (ICS) + slope range of 16-20%

Note that:

[1]Traditional conservation structure (TCS) used in the area was furrow made by farmers with no application of soil and water conservation (SWC) design principle. The furrow was prepared by a farmer himself by using oxen. Its approximate width and depth were 30cm and 15cm respectively. All the six farmers hosting the trial applied furrow as TCS treatment.

[2]Introduced conservation structure (ICS) used in the area was soil bund. Its dimension was 2m lengthx40cmx40cm. The number of bunds made in each plot as treatment was 3. The millet was sown by broadcast in the field at seed rate of 22kg/ha

2.6 Replications

Three treatments under slope category of above 10-15% were replicated three times. Similarly, three treatments under slope category of above 15-20% were replicated three times. The replication plot had similar treatments.

2.7 Data collected from runoff plots

The actual measurement of sediments in the catch pits was done starting from the time of sowing to the time of harvesting of millet. Frequently, the soil was removed from catch pits and collected on sack for convincing FRG members during visiting. Small holes were made on the plastic sheet and placed in pit to catch only sediments and percolate water. During weighing sediments in the collection pit, a sample of wet soil was taken for drying and to use the difference of wet mass and dry mass and then to multiply other data of wet mass as a correction factor. The soil sample data was taken from the pits of six farmers' plot for taken to laboratory for nutrient analysis. The analysis was done for Total N, OM, texture, av K, av P, P^H and Exchangeable acidity as well as Al. The bulk density of the sample soil was also measured for the area.

2.8 Analysis of the result

The statistical analysis was made using SAS software for scientific purpose while simple statistics like the maximum, minimum, mean and mode were used for comparing of soil loss from different experimental plots to convince farmers. Soil nutrient content of collected sample was interpreted using nutrient rating values or ranges in laboratory manual.

Similarly, for cost benefit analysis, the result of lost nutrients (N amount lost) was used. The economic value of soil loss was determined by using economic equivalence of the current cost of artificial fertilizers. The nutrients other than NPK (OM, texture, P^H, Exchangeable acidity and Al were used as indicators of the effect of soil erosion on acidity and textural change, on fertility decline. In addition, the collected volume of soil was changed to depth of soil layer to indicate the soil capital lost using the following formula.

Volume= Depth x Length x Width; where Length x Width = Area. And,

$$\text{Depth (m)} = \frac{\text{Volume (m}^3\text{)}}{\text{Area(m}^2\text{)}}$$

3. Results and Discussion

3.1. Land holding and its characteristics in shomba kebele

The average total land holding size in shomba kebele was 3.14ha with the minimum 0.125ha and the maximum 7ha while the mode is 0.125ha. As indicated in appendix 4, the average slope category of the area was 25% (1-7% slope), 42% (8-15% slope), 29% (16-33% slope) and 4% (>33% slope). This indicates that, more than 71% of the land was having the slope more than 10% which need critical attention on soil and water conservation before cultivating of crops.

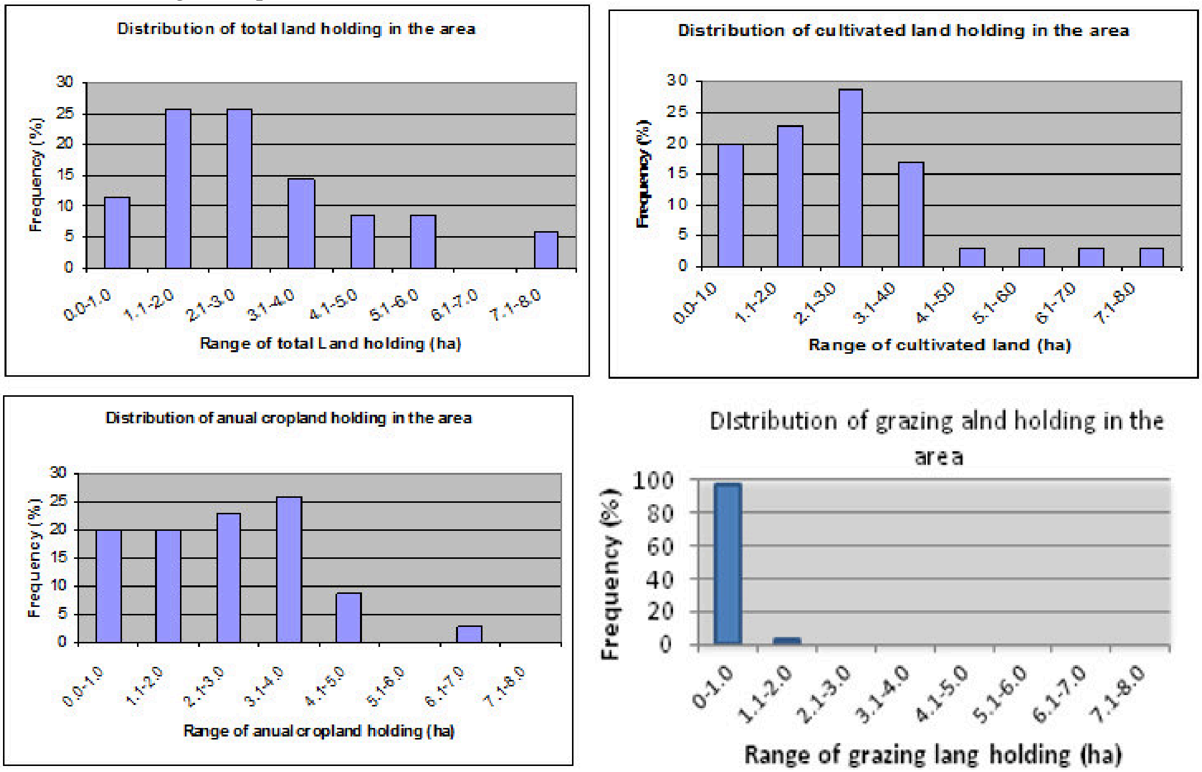

Figure 3: The histogram indicating the range of land holding of the HHs

The figure 3 above shows that most farmers land holding resonates between 1-2ha which indicate shortage of land. This is also the driving force for cultivation of slope land in the area leading to high soil erosion.

4.3. Crop production system

Out of the interviewed farmers 60% responded that they start land preparation for maize after 15th January while 40% said that they start first tillage at the start of February indicating that Jan-Feb is accepted season for starting of tillage for maize. The sowing time for maize is from start of March to April15. It is harvested on October-November. The idea of majority have common agreement on start of cultivation for Millet in January and sowing time in April-May with at least the frequency of tillage four times. Its harvesting time is in September-October. In the case of Pepper, land preparation for seedling start in March and planting in Jun-July after cultivating the land at least 4 times. Its harvesting period is at October-November (Table 1). Millet, maize and pepper contributed to 90% of the farmers' income while 8% from livestock and 2% from off farm income. According to the information from participant farmers, they use at least 40% of the crop produce for sale to the household while 60% for own consumption. Although they have minimum contribution, some farmers produce coffee, soybean and other fruits for cash.

Table 1**:** Cropping calendar for major crops in the area

Activity	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Land preparation												
Maize		x	x									
Millet			x	x								
Pepper			X	x								
Sowing												
Maize			x	x								
Millet				x								
Pepper				x								
Weeding												
Maize					x	x						
Millet					X	x	X					
Pepper					x	x		X				
Harvesting												
Maize										X	x	
Millet									X	x		
Pepper										x	x	

4.4. Rainfall and temperature characteristics of the area

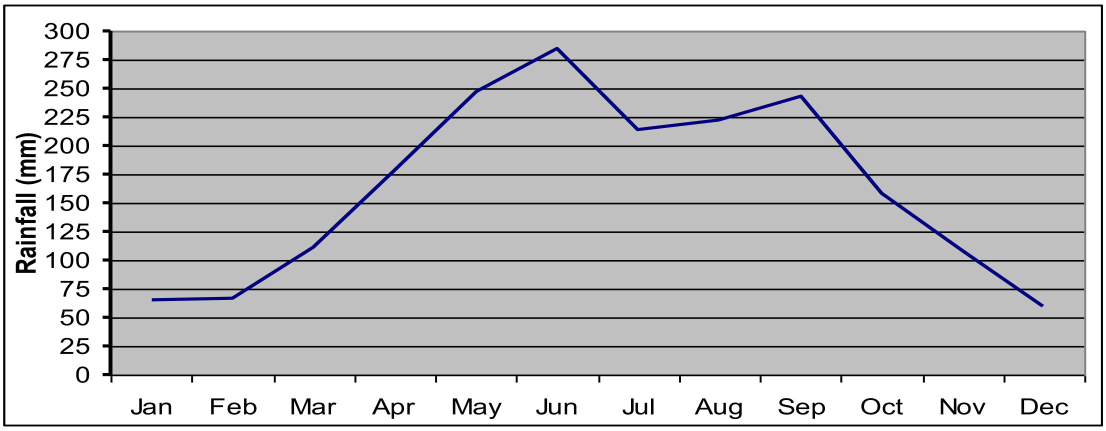

Figure 3: Mean monthly rainfall of the area (Source of data: Kafa zone,Wushwush Rainfall Station**)**

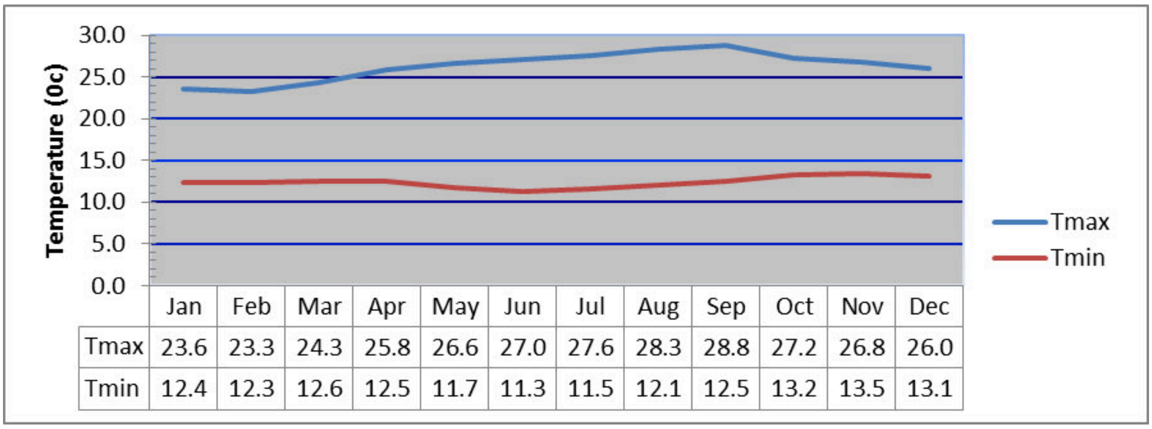

Figure 4: Mean monthly average maximum and minimum temperature of the area (Source : Kafa zone,Wushwush Rainfall Station)

The rainfall of the area has one long rainy season with two relative peaks (June with 284mm and September with 243mm. The rainy season starts from March and end October (Figure 3). As it was said, the crop production was highly affected by flood especially June-July unless protective measures were prepared on the farm. During this period Millet and pepper are the most affected crops because the land is open in both cases than the maize which developed the cover.

3.2. Soil erosion occurrence in the area

The area has high soil erosion problem during millet production. The main reason for the occurrence includes high rainfall, high frequency of land preparation for millet sowing (4-5 times) and cultivating this millet on slope land due to shortage of farmland for crop production. The soil loss data collected in this study indicates that more than 70% soil erosion occurs in the first month after millet sowing.

3.3 Extent of Soil erosion in the area under millet production

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4859.0	971.81	10.47	0.0005**
Slope	1	2713.3	2713.38	29.24	0.0002**
Replication (Farmers)	2	200.33	100.16	1.08	0.3706
SWC practices	2	1945.33	972.66	10.48	0.0023**
Error	12	1113.44	92.78		
Corrected Total	17	5972.50			

For slope below 15%	
Treatments	Mean soil loss (t/ha/yr)
Free of any SWC practice	25 a
Farmers practice (furrow making) of SWC	21 b
Introduced SWC of constructed soil bund	15 c
LSD 5%	24%
CV %	24%
For slope above 15%	
Treatments	Mean soil loss (t/ha/yr)
Free of any SWC practice	61 a
Farmers practice (furrow making) of SWC	53 a
Introduced SWC of constructed soil bund	21 b
LSD5%	19 %
CV%	43%
CV% of all treatments	57%

**significant at o.o1; *significant at 0.05

In general, there is highly significant difference at (p=0.01) among and between application of different treatments (p = 0.0005). It was indicated in the table that, there was highly significant difference between treatment (p=0.0023) as well as the block factor (slope) with p=0.0002.

According to LSD at p=0.05, the mean of three treatment over area was statistically different from each other (indicated by different letters) in the table above. The soil loss under millet production was observed to be 61ton/ ha/yr under untreated plot (free plot), 53t/ha under farmer practice and 21t/ha under introduced erosion control plot (Appendix 1).it was known that the national soil loss tolerance according to (Hurni, 1983; 1988) is 12-18t/ha/yr while 16t/ha/yr was obtained in forest dominated south western Ethiopia. The mean of soil loss under three different treatments over three farmers in slope below 15% was 21t/ha. Similarly, the mean of soil loss under three different treatments over three farmers in slope range above 15% was 45t/ha indicating that effect of slope on soil erosion to be more than double.

3.4 Effect of different SWC practices on the soil erosion

This means under similar farming system on millet production cultivating on untreated land with slope greater than 15% has more than two fold soil losses than that of 10-15% slope. The soil loss from any land under millet production varied from that of introduced type of soil conservation and farmer practice of soil conservation methods by 40 and 32t/ha respectively. This shows that during millet production on slope land greater than 15%, areas treated by farmer practice and those untreated by any conservation practice exceeded that of introduced soil conservation practice by 150% and 190% respectively. It can be inferred from the result that, when compared to untreated millet production field, by applying their practice of soil erosion control, farmers could save at least 8t/ha soil from slope land and 4t/ha soil from less slope land during millet production.

According to LSD at p=0.05 method of mean separation, three treatment have no approaching values of soil loss and therefore, they are statistically different from each other (indicated by different letters) in the table below. This indicates that, at slope range 10-15% there exists soil erosion that could affect the production. The soil loss from any land under millet production will vary from that of introduced type of soil conservation and farmer practice of soil conservation methods by 15 and 4t/ha respectively. Areas treated by farmer practice and those untreated will exceed that of introduced soil conservation area by 40% and 60% respectively. Farmers during discussion rose possible causes of soil loss in the area were

- Frequency of tillage during millet production (4-5tmes)
- Millet is sparsely planted and open throughout the production times and this situation aggravates erosion
- Compaction of soil (trampling by animals) during planting
- Cultivation of high slope (>15%) farm land for millet
- High and erosive rainfall during the planting season (Jun/July)

3.5 Soil capital lost

Table 2: The volume of total collected soil to determine soil capital /layer/ lost (mm)

	Trial farmer	**Soil layer lost per plot (Millimeter) ***
1	A	2.66
2	B	2.78
3	C	1.73
4	D	1.41
5	E	2.48
6	F	1.42
	Average	2.2
	Average Soil layer lost (mm)*	2.2mm soil layer lost in one year

* Average soil depth lost = Average soil volume lost divided by plot area and converted to unit of (mm)

3.6 Soil analysis result

The analysis of soil nutrient that was lost from the plots indicated that, its texture was sandy clay loam with bulk density 1.4g/cm^3. The PH of the soil lost ranges between 5.2-5.6 with OM and N content being very good (above 3% OM and above 0.2% N) compared to P and K which are under category of medium and low respectively. However, the CEC of the soil was high (>30) indicating good capacity of soil to support crop production.

Table 3: Average nutrient contents of soil collected from the runoff plot

Trial farmer	Slope range	PH water (1:2.5)	Ppm p (Bray II)	% OC	% OM	% N	Available k (Meq k/100 gm)	CEC (Meq/100gm)
D	>10-15%	5.60	4.70	6.18	4.55	0.20	0.69	28.56
C	>10-15%	5.44	5.37	2.64	8.44	0.32	0.69	32.88
F	>10-15%	5.56	5.24	2.19	9.43	0.26	0.17	37.56
E	>15-20%	5.41	9.80	4.90	9.51	0.24	0.56	43.08
B	>15-20%	5.69	11.95	5.47	10.65	0.21	0.07	39.86
A	>15-20%	5.20	13.03	2.85	3.78	0.17	0.43	36.60
Summary	Max	5.69	13.03	6.18	10.65	0.32	0.69	43.08
	Min	5.20	4.70	2.19	3.78	0.17	0.07	28.56
	Average	**5.47**	**8.48**	**4.08**	**7.60**	**0.24**	**0.42**	**36.27**

3.7 The economic value of lost soil

From the table below it was clearly observed that an average of 95.6kg N, 0.41kg P and 44.4kg K were lost per hectare of land under millet production. This on the other hand shows the need of n application on the area using 200kg urea (100kg Urea has 46kg N and to get 96kg N which was lost by erosion it is 200Kg Urea). This indicates that a farmer with such soil erosion in the area will invest 30kg N (65kg Urea) more than blanket recommendation on his land to maintain fertility of his land. It will be 142% cost of fertilizer relative to normal application rate.

Table 4: Data of macro-nutrient lost from runoff plot by soil erosion under millet production

Trial farmer	N (%)	P(ppm)	K (Meq k/100gm)
A	0.24	9.8	2.56
F.	0.32	5.37	2.69
C	0.2	4.7	2.69
B	0.21	11.95	3.07
D	0.26	5.24	2.17
E	0.17	13.03	2.43

Table 5: Summary of lost nutrients from eroded soil

Amount of nutrients lost per ha in kg			
Trial farmer	N (kg)	P (kg)	K (kg)
A	148.8	0.61	61.9
F.	76.8	0.13	25.2
C	54	0.13	28.3
B	144.9	0.82	82.6
D	62.4	0.13	20.3
E	86.7	0.66	48.3
Average	95.6	0.41	44.4

3.8 Farmers' suggestion towards reducing the erosion during discussion at FTC

FRG member farmers decided during the awareness creation at FTC that, awareness should be extended to other millet producer farmers about the problem of soil erosion. Similarly yield comparison experiment should be continued for making soil erosion problem in the area explained clearly. The agreed to make survey of their land and act according to the expert's suggestion during millet production as well as to produce millet on less slope lands while some others not to produce it since it aggravates erosion. They also raised the issue of making local furrow spacing with 2-3m interval to save soil while producing millet.

4. Conclusion and Recommendation

Millet production on slope land (greater than 15%) could aggravate soil erosion in the kafa zone Gimbo woreda shomba kichib kebele. On average, 57 ton/ha/yr soils was lost from millet production slope land leading to more investment of 42% fertilizer as additional on 100% recommended rate for N (Urea). This shows that unless a farmer cost more 42% money on his land he could not get his land fertile for crop production. Farmers during discussion rose possible causes of soil loss in the area were, frequency of tillage during millet production (4-5tmes); Millet is sparsely planted and open throughout the production times and this situation aggravates erosion; Compaction of soil (trampling by animals) during planting; Cultivation of high slope (>15%) farm land for millet and the high and erosive rainfall during the planting season (Jun/July) therefore, the following points were recommended;

- Millet production should be done with proper SWC works
- Slopes above 15% should be treated with 5-6m Contour interval for SWC activity
- Trampling by animals should be avoided or reduced
- Awareness creation on soil and water conservation should be continued at FTC level
- During watershed development planning, special attention should be given for millet producers
- Use of strip cropping with width of the strip for a give crop (millet or other) not more than 10m
- Farmers need to be organized for further agricultural experiment through FRG principle as it empowers the to solve their own agricultural productivity problem
- Furthermore, farmers should be also convinced with yield comparative study on treated and untreated plots from soil erosion in the area.

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