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Effects of water erosion on soil chemical loss under different tillage and cropping system in clay loam soil at Assosa, Ethiopia

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ABSTRACT

Soil erosion affects the sustainable use of soil resources through its influence on soil properties. Proper use of tillage can improve soil related constraints, while improper tillage may cause a range of undesirable processes. Conservation tillage like no tillage had been reported to improve the properties of the soil. Thus, the study had been carried out at Assosa Agricultural research center to evaluate the effects of tillage and cropping system on soil chemical and in situ moisture conservation. Eighteen experimental runoff plots of 8 m long and 3 m wide each were framed with corrugated iron sheets. The experimental design used was randomized complete block design (RCBD) with six treatment in factorial combinations vis-à-vis three cropping systems (sole maize, sole soya bean and intercropping of maize with soya bean), with tillage system (no tillage and convectional tillage), that were replicated three times. The treatments had shown non-significant variation for all parameters showing Enrichment ratio of ≥ 1 except some no tillage treatments. Higher enrichment ratios for clay and silt fraction were observed under conventional tillage treatments and thereby high loss of nutrients like nitrogen, available phosphorus, and organic carbon than no tillage treatments. No tillage with soya bean and no tillage with intercropping treatments had shown the value of ≤ 1 for total nitrogen and phosphorus than conventional tillage treatments. No tillage treatments in concomitant with cropping system especially intercropping had retained more nutrients than conventional tillage by reducing runoff and soil loss to Enrichment ratio of ≤ 1.This study revealed the potential of no tillage with mulch to reduce nutrient losses and enrichment ratio.

Key Words: *Water erosion, Tillage, Soil nutrients and Land degradation*

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I. Introduction

Land degradation in the form of soil erosion and declining soil quality is a serious challenge to agricultural productivity and economic growth throughout the world especially in developing

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countries while water is significant resource for agriculture (Hossain and Siddique, 2015; Siddique et al., 2014). Soil erosion and declining soil quality are the major constraints for crop production and sustainable land management in Ethiopia.Organic matter differs in stage of decomposition and degree of association with mineral material (Kay and Vanden Bygaart, 2002). These different forms of soil organic matter (SOM) collectively represent a reservoir of nutrients that are critical for plant growth. The tillage impacts on SOM varied due to soil type, cropping system, residue management and climatic conditions (Marschne et al., 2008). Tillage systems that reduce soil disturbance and residue incorporation have generally been observed to increase SOM content (Mrabet et al., 2001). Ismail et al. (1994) concluded that conservation tillage system results in significant and positive effects onseveral chemical soil properties. Carter (1992) reported that conservation tillage practices may lead to high soil organic carbon (SOC) contents in surface soil than conventional tillage system or mould board plough. Soil quality, erosion and the loss of SOM due to tillage may be considered to be a function of soil type, climatic condition and cropping practice (Siddique et. al., 2017; Lal et al., 1998). Short term influence of tillage on transfer of soil carbon to atmospheric CO_2 in semi -arid soil is small (Ellert and Janzen, 1999).

Therefore long term conservation tillage practices were highly effective in improving SOC under semi-arid environment (Moreno et al., 1997). The conversion to no-till may increase SOC pool by about 10 Mg ha^{-1} in 5-20 years (Paustian et al., 1997). Conflicting results also exist regarding tillage practices and SOM content in surface soil. Dick (1983) reported higher organic C and N contents in no-tillage than conventional tillage system. Conventional tillage practices have resulted in lower carbon contents of agricultural soils due to increased decomposition rates and carbon redistribution (Christensen, 1996). The SOM largely contributes to nutrient cycling and thus supply of N, S and other elements as well; while total N and cation exchange capacity determination is important for soil management and fertilizer recommendation (Saleque et al., 2009; Siddique, 2015; Sultana et al., 2015). Soil cultivation reduces organic matter and alters distribution and stability of soil aggregates (Six et al., 1999; Siddique et al., 2017). The most common method to enhance SOM is crop rotation, residue management and the application of farm manure (Kirchmann and Witter, 1992). The ability of soil to retain nutrients is increased by addition of organic materials and this play a major role in reducing soil erosion and maintaining long term soil health and productivity. Improved nutrient management and soil conservation practices are gaining importance in research and policy communities (Khan et al., 2007). Soil pH influenced the solubility of phosphorus, iron, manganese, zinc and many other nutrients (Lindsey, 1979). Verma and Bhagat (1992) reported that the incorporation of rice straw in wheat caused a slight increase in an availability of P, Mn and Zn and a marked increase in the availability of K. There is a need to combine tillage practices with nutrientmanagement practices, including recycling of crop residues in energy conscious world. The effects of tillage systems and residue retention on soil properties were investigated, because there is little information on this subject in Ethiopia. This investigation was therefore undertaken to determine the effects of tillage and residue management on soil chemical properties in soyabean- maize cropping systems. The objective of the study was to examine the effect of soil chemical loss as influenced by water erosionunder different tillage practices and cropping systems.

II. Materials and Methods

Study area: The study was conducted at the Assosa Agricultural Research Center (ASARC), which is located in Assosa District at Benishangul-Gumuz Regional State (BGRS). The ASARC is located in the western part of Ethiopia from 10º 01' 25'' to 10º 02' 50'' north latitude and from 34º 33' 50'' to 34º 34' 35'' east longitude. The study area covers a total land area of 202.5 ha with geology of Tarmabe basalt, sometimes porphyritic of the Miocene to Pliocene period. The Assosa District is characterized by hot to warm moist lowland plain with uni-modal rainfall pattern. The rainy season starts at the early May and lasts at the end of October with maximum rainfall in the months of June, July, and August. The total annual average (2000-2007) rainfall is 1316 mm. The annual mean minimum and mean maximum temperatures of the District for the periods from 2000 to 2008 were 16.75 and 27.92 ^{0}C respectively. The soil type of the study area was characterized as Nitisol.

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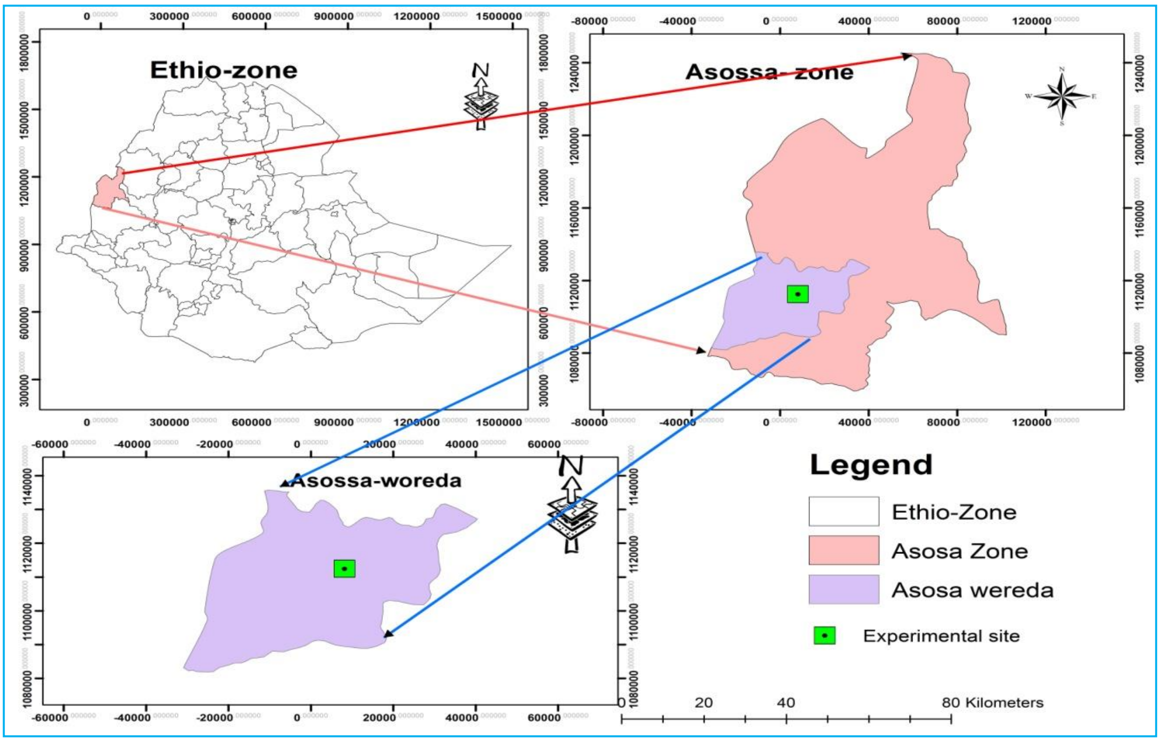
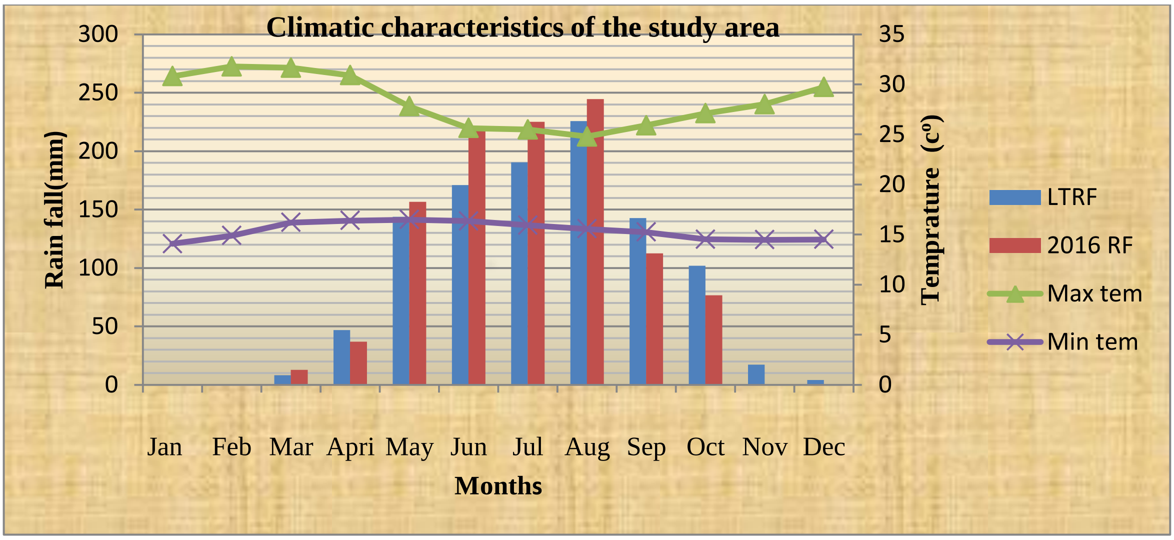


Figure 01. Location map of experimental site.



LTRF= Long term rainfall, Max tem= maximum temperature, Min tem= minimum temperature, rf = rain fall

Figure 02 . Long term (1983-2016) average rainfall and temperature and one year (2016) rainfall of Assosa Agricultural Research Center (1983-2016).

Experimental setup: The experiment had 6 treatments combinations and three replications with the total experimental plots of 18. The experimental plots were applied to runoff plots of 3m x 8m dimension that was laid out by completely randomized block design (RCBD) in factorial combination. The treatments were:

1. T1: Conventional tillage (the farmers local tillage practice to sow maize) + sole crop (maize)
2. T2: No tillage (tilling the place where to put the seed only, (2.5 t/ha)) + sole crop (maize)
3. T3: Conventional tillage (the farmers local tillage practice for both test crops) + Intercropping (maize +soybean)
4. T4: No tillage (tilling the place where to put the seed only, (2.5 t/ha) + Intercropping (maize +soybean)
5. T5: Conventional tillage (the farmers local tillage practice to sow soya bean was used) + sole soybean)
6. T6: No tillage (tilling the place where to put the seed only, (2.5t/ha)) + sole crop (soybean)

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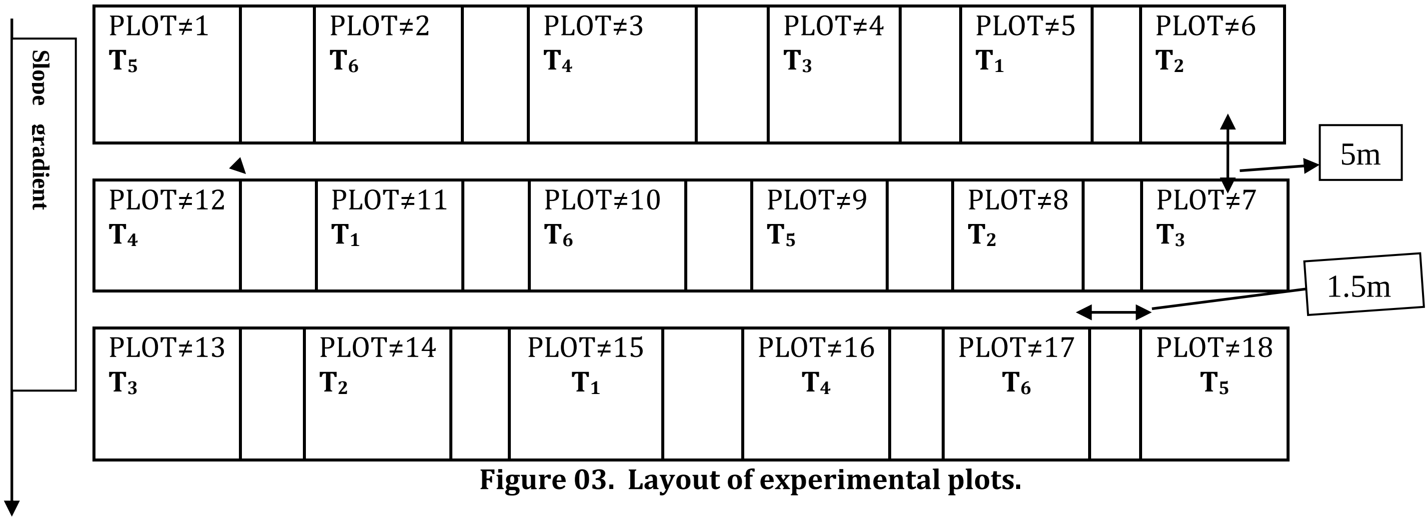

Figure 03. Layout of experimental plots.

Test plots arrangement and management: The study was carried out by using RCBD in factorial combination with different surface management practices and cropping system as the experimental factors on 7% slope of land. It had 6 treatment combinations with three replications. There were two tillage practices (no tillage along with 2.5 tonnes of soya bean straw mulch, conventional tillage (the farmers local practice for the test crop) and three cropping system (sole maize, sole soya bean, and intercropping of maize and soya bean). The study was carried out in hydrologically isolated experimental runoff plots of 3m x 8m.

Tillage operation used was oxen plow (Maresha) for conventional tillage practice of all cropping systems to a depth of 15 cm (triple passes) for maize and 12 cm (double passes) for soya bean, whereas pickaxe was used for all no tillage treatments at sowing for maize to a depth of 10 cm and hoe for soya bean to a depth of 7 cm. The tillage frequency used for soya bean and maize were two and three times as the farmer's local practice of the area for conventional tillage. Hand hoeing was used for weeding for all treatments.

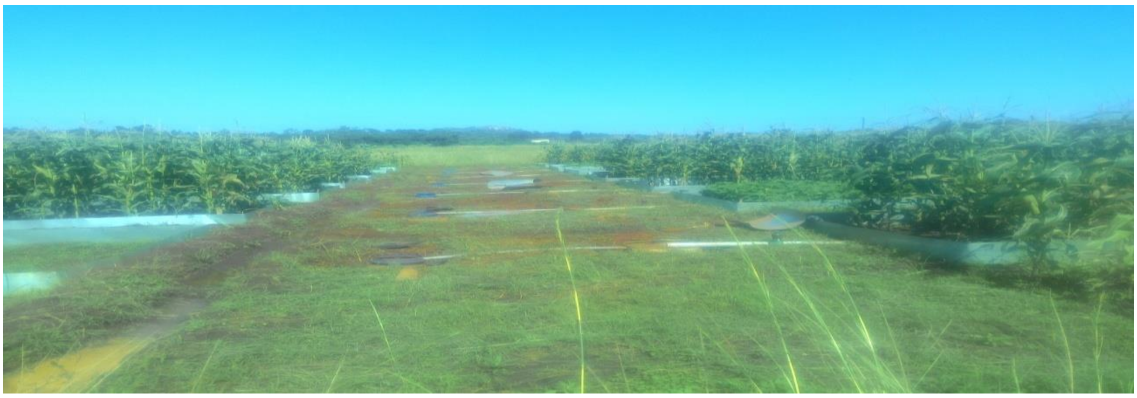

Figure 04. Establishment of runoff plots.

Meteorological parameters like precipitation, maximum and minimum temperature were collected from the meteorological station of Assosa Agricultural Research Center which was found in the vicinity of the experimental site. Precipitation is much more important than the other metrological parameters because rainfall has a direct relation with runoff and sediment generation from the experimental plots.

Data collection: Soil pH was potentiometrically measured in the supernatant suspension of 1:2.5 soil: water ratio (Motsara and Roy, 2008). Organic carbon content of the soil was determined by potassium dichromate wet combustion procedure (Walkley and Black, 1934). The available phosphorus content of soils was determined by 0.5M sodium bicarbonate extraction procedures (Olsen et al., 1954). Total nitrogen content of the soil was determined by wet oxidation procedures of the Kjeldahl method (Motsara and Roy, 2008).

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Enrichment ratio: A nutrient enrichment ratio (ER) was determined for each plot by dividing the average concentration of a nutrient in the sediment by the average nutrient concentration of in-situ soil after harvest as:

$$ER = Ncs/Nci \qquad (1)$$

Where, Ncs = the concentration of a constituent in the sediment
Nci = the concentration of the same constituent in the in situ soil after harvest

Data analysis: All measured parameter were subjected to statistics' version 8 and treatment means was compared using the least significant difference at the 5% probability level (LSD 0.05) where the variance ratio for treatment effects shows significance.

III. Results and Discussion

Soil chemical properties prior to the experiment

Chemical analyses (Table 01) showed that the nutrient contents of the experimental plots were generally low when compared with the standard values. The soil pH (H_2O) was acidic with mean value of 5.77 which reveals the moderately acidic. This type of soil is characterized by low fertility status. It had low organic carbon, total nitrogen, and available phosphorus that could be associated with the low organic matter content, the loss of N due to the surface runoff, leaching, and removal by crop (Deckers et al., 2001; Eylachew, 2001; Fageria and Baligar, 2005).

Table 01. Chemical properties of experimental plots prior to the experiment

Treatments	pH (H_2O)	OC (%)	N (%)	P_{av} (mg kg^{-1})
Conventional tillage with maize (T1)	5.74	1.15	0.15	0.24
Conventional tillage with soya bean (T5)	5.75	0.59	0.14	2.32
Conventional tillage with intercropping (T3)	5.91	0.76	0.15	0.36
No tillage with maize (T2)	5.79	0.78	0.15	0.26
No tillage with soya bean (T6)	5.8	0.32	0.17	0.46
No tillage with intercropping (T4)	5.65	0.51	0.16	0.3
Mean	*5.77*	*0.68*	*0.15*	*0.32*
CV (%)	*1.48*	*41.4*	*6.73*	*24.56*

pH: Power of hydrogen, OC: organic carbon, N: nitrogen, P: phosphorus, CV: coefficient of variation

Chemical properties of in situ soil after harvesting

Analysis of variance showed non-significant variation among treatments for all parameters. Even though, there was no significant difference among treatments, as indicated in Table 02, nutrient analysis after harvesting showed high removal of sediments under conventional tillage than no tillage for almost all of the parameters. Treatments were significantly different for total nitrogen, and available phosphorus, having direct relationship with in situ clay and silt fraction percentages.

Result reveals that high amount of nutrient were retained under no tillage treatment as compared to conventional tillage treatments after harvesting which is directly related to removal of finest soil particles by water erosion (sheet and rill erosion) from the experimental plots (Table 03). These study in lines with the study of (Flanagan and Foster, 1989) who reported clay and silt fraction as very finest soil particles rich in nutrient. Using no tillage had retained more nutrients by (11.1, 12.36 and 10.52 % for total nitrogen, 23.31, 26.49 and 26.89 % for available phosphorus and 12.37, 26.05, and 26.82 % for organic carbon) as compared to conventional tillage under sole maize, sole soya bean and their intercropping respectively.

Results of the study are in agreement with those conducted in different studies at different countries. Conservation tillage (zero and minimum tillage) in farming systems had illustrated the greater

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opportunity to increase soil extractable phosphorus (P) due to accumulation of crop residues at the soil surface compared with conventional tillage (Bahrani et al., 2007). Rasmussen (1999) and During et al. (2002) had also observed that with annual no-tillage, plant residues left on the soil surface increase the organic matter in the topsoil. Due to its mobile characteristics, losses of nitrogen (N) by erosion are estimated to range from 1 to 100 kg ha^{-1}year (Rose and Dalal, 1988) implicating erosion as a major cause of long-term decline in the fertility of agricultural soils.

Table 02. Some chemical properties of in-situ soil after harvesting the test crops

Treatments	pH (H_2O)	OC (%)	N (%)	Pav (mg kg-1)
Conventional tillage with maize (T1)	5.65	0.85	0.16	3.74
Conventional tillage with soya bean (T5)	5.77	0.88	0.16	4.25
Conventional tillage with intercrop. (T3)	5.63	0.90	0.17	5.32
No tillage with maize (T2)	5.88	0.97	0.18	5.33
No tillage with soya bean (T6)	5.78	1.19	0.186	16.04
No tillage with intercropping (T4)	5.94	1.23	0.19	19.78
LSD (0.05)	*ns*	*ns*	*ns*	*ns*
CV (%)	*2.05*	*47.54*	*7.9*	*103.51*

pH: Power of hydrogen, Oc: organic carbon, N: nitrogen, P: phosphorus, CV: coefficient of variation LSD : Least significant difference

Effects of tillage and cropping system on Sediment Enrichment ratios (ER)

Table 03. Interaction effect of tillage and cropping systems on Enrichment ratio

Treatments	OC	N	P_{av}	Mechanical composition		
				sand	silt	clay
Conventional tillage with maize (T1)	2.18	1.9	3.45	0.53	3.37	1.78
Conventional tillage with soya bean (T5)	1.89	1.8	1.94	0.55	3.39	1.74
Conventional tillage with intercropping (T3)	1.83	1.66	0.66	0.52	3.19	1.6
No tillage with maize (T2)	1.63	1.56	1.04	0.67	2.16	1.39
No tillage with soya bean (T6)	1.11	1.5	0.22	0.71	1.91	1.31
No tillage with intercropping (T4)	1.04	0.9	0.19	0.73	1.86	1.26
LSD $_{(0.05)}$	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
CV (%)	*56*	*25.3*	*115.25*	*24.8*	*36.9*	*17.9*

ER of ≥ 1 was observed for all parameters except for sand and nitrogen under intercropping. The factors had shown non-significant variation among treatments. Higher enrichment ratios for clay and silt fraction were observed under conventional tillage treatments thereby high loss of nutrients like nitrogen, phosphorus, and organic carbon than no tillage treatments. Even though, Enrichment ratio value of ≥ 1 observed under some of the treatments, no tillage with soya bean and no tillage with intercropping had shown the value of ≤ 1 for total nitrogen and available phosphorus than conventional tillage treatments. No tillage treatments in concomitant with cropping system especially intercropping had retained more nutrients than conventional tillage by reducing runoff and soil loss which is related with the report of (Kosmas et al., 1997) who point; out runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases.

As the Table 03 reveals, the Enrichment ratio of phosphorus is high especially for conventional tillage treatments ranging from 0.66 to 3.45 and 0.19 to 1.04 for no tillage treatments which coincides with

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Haregeweyn et al. (2008) report of the higher ER values of Pav in the Northern Ethiopia. Also, Gachene et al. (1997) reported the highest ER value 10.3 for Pav in a paleustalf of central Kenya.

Next to nitrogen, phosphorus is often the most limiting nutrient for crop production in most of Ethiopian soils (Tekalign et al., 2002); yet as observed in this study, it was the most vulnerable to losses through erosion warranting intensive applications of phosphate fertilizers. Nutrient losses may be even greater than that reported in this study, as only part of the nutrients lost with the sediments (not the part that was dissolved in runoff) was considered. Therefore, ER value of less than one that was observed for some of the nutrients like N and P under some of the treatments does not show the tendency of the nutrient remained in the in-situ soil, when the sediment is eroded.

IV. Conclusion

Soil nutrient contents of the experimental plots were generally low when compared with the standard rated values. The soil P^H (H_2O) was acidic with mean value of 5.77 which reveals the properties of Nitisol of the study area which is characterized by low fertility status. Treatments showed non-significant variation on chemical properties and mechanical composition of the soil. Even though, there is no significant difference statistically, high percentages of nutrient loss were observed under conventional tillage practices as compared to no tillage practices with the same cropping systems. No tillage had reduced the loss of nutrient by (10, 4 and 39.3 % for nitrogen, 63.8, 35.1 and 32.4 % for available phosphorus, and clay fraction by 6.3, 4.3 and 5.26 %) under sole maize, sole soya bean and their intercropping respectively. As the study reveals, under no tillage treatment less percentage of clay fraction had been lost by erosion which coincides with high loss of nutrients under conventional tillage system. The result reveals, high amount of nutrient retention under no tillage treatment compared to conventional tillage treatments after harvesting/erosion which is directly related to removal of finest soil particles by water erosion (sheet and rill erosion) from the experimental plots. Using no tillage had retained more nutrients by (11.1, 12.36 and 10.52% for total nitrogen, 23.31, 26.49 and 26.89% for available phosphorus and 12.37, 26.05, and 26.82% for organic carbon) as compared to conventional tillage under sole maize, sole soya bean and their intercropping respectively. Treatments had shown non-significant variation for enrichment ratio of all parameters. Higher enrichment ratios for clay and silt fraction were observed under conventional tillage treatments thereby high loss of nutrients like nitrogen, available phosphorus, and organic carbon than no tillage treatments. No tillage with soya bean and no tillage with intercropping had shown the value of ≤ 1 for total nitrogen and available phosphorus than conventional tillage treatments. No tillage treatments in concomitant with cropping system especially intercropping had retained more nutrients than conventional tillage by reducing runoff and soil loss to Enrichment ratio of ≤ 1.

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