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Effects of Different Soil Management Practices Under Maize-Legume Production System on Rainfall-Runoff and Soil Loss Relationships in Bako, West Oromia, Ethiopia

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Abstract
Soil erosion is one of the major factors responsible for soil degradation and becomes a threat to human survival. Sustainable soil management systems must be developed to reduce degradation and restore the productivity of the eroded land. Therefore; this study was carried out under natural rainfall conditions with the objective of investigating and evaluating the effects of different soil management practices on runoff, soil, nutrient losses at Bako, Ethiopia. Eighteen experimental runoff plots of 8 m length and 3 m width each were framed with corrugated iron sheets. The experimental design used was randomized complete block design (RCBD) with six treatments namely; sole maize conventional practices (SMCP), sole haricot bean conventional practices (SHCP), maize-haricot bean conventional practices (MHCP), maize-mulch conventional practices (MmCP), maize-haricot bean conservation agriculture (MHCA) and maize-mulch conservational agriculture (MmCA) that were replicated three times. Parameters observed included soil loss, runoff depth, and nutrient losses. The results revealed that there was a significant difference at ($P<0.05$) between the treatments regarding their effect on runoff depth, soil loss and sediment associated nutrient losses. The seasonal runoff depth ranged between 22.12 and 44.99 mm while the seasonal soil loss varied between 4.04 and 18.92 t/ha during the entire study period. The loss of nutrients and organic carbon (OC) were in the range of 82.719 to 368.747 kg/ ha for OC, for total N (TN) 7.550 to 33.538 kg/ ha, available P, 0.039 to 0.179 kg/ ha and 3.230 to 14.230 kg/ha for available K. The results showed that MHCP, SHCP, MmCP, MHCA and MmCA could control the runoff by the order of 50.83, 36.89, 24.13, 20.25 and 9.40% in comparison to SMCP. Treatments reduced the soil loss in the following order; MHCA > MHCP > SHCP > MmCA > MmCP which was 78.64, 75.21, 62.84, 49.47 and 47.99 % respectively. MHCA had higher reduction potential of nutrients for P, K, OC and TN which was 78.41, 77.30, 77.57 and 77.49 % respectively as compared to SMCP of farmer practices. The results indicated that practicing conservation agriculture can be used as better soil and water conservation tool to effectively check soil and nutrient losses under the existing slope and rainfall conditions in Bako area in Ethiopia.
Keywords: Soil erosion, Tillage practices, runoff, soil loss and nutrient loss

1. INTRODUCTION

Soil erosion is one of the major factors responsible for soil degradation and becomes a threat to human survival (Lal and Pierce, 1991). Ethiopia has a total surface area of 111.8 million hectares; of which 60 million hectares are estimated to be agriculturally productive. Out of the estimated agriculturally productive lands, about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return; with an estimated total loss of 2 billion m^3 of top soil per year (Fikru, 1990; Sertsu, 2000). Accordingly; based on the nutrient contents and ranges of soil losses in high lands of Ethiopia it was estimated the annual nutrient losses due to erosion to be in the range of 36 to 429 kg/ha of N, 0.412 to 5 kg/ha of available P and 1.4 to 17 kg/ha of exchangeable K.

Sustainable soil management systems must be developed to reduce degradation and restore the productivity of the eroded land (Montgomery, 2007). Therefore, the scientific community must develop agricultural technology to: reduce input while maximizing economic returns, decrease soil degradation, minimize risks of pollution of natural waters and environments, restore productivity of degraded land and maintain productive capacity of existing land by preserving a soil's life support processes.

The western part of Oromia region is known by its high amount of rainfall and the study area is found in this range of rainfall which results high amount of soil loss, water loss and nutrient loss due to surface runoff as well as poor tillage practices. To this effect, no systematic study on effect of different soil management system under maize-legume production on runoff, soil and nutrient loss in soil and climatic conditions of Bako area had been made so far. Accordingly, this study was carried out under natural rainfall conditions with the objective of investigating and evaluating the effects of different soil management practices on runoff, soil, nutrient losses at Bako.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The experiment was conducted at Bako Agricultural Research Centre (BARC) during the year 2012 main cropping season, which is geographically located in Oromia Region on the western part of Ethiopia at about 9° 00' to 9° 10' N latitude and 37° 00' to 37° 9' E longitudes and a distance of 250 km away from Addis Ababa at an altitude of 1650 m above sea level (a.s.l) (Figure 1). The long-term weather information revealed that the area has a unimodal rainfall pattern, and mean annual rainfall was observed as 1273mm. The rainy season covers from April to October, and maximum rain was received in the months of June, July and August. It has a warm humid climate with annual mean minimum and maximum temperature of 13.5 and 23.7 °C, respectively as per BARC metrological data record. The area is known for its mixed crop livestock farming system and the major annual and perennial crops grown in the study area are maize (*Zea mays*), sorghum *(Sorghum bicolor* L. Monch.*)*, teff *(Eragrostis tef* (Zucc), niger seed (*Guizotia abyssinica,* L.), haricot bean (*Phaseolus vulgaris,* L), hot pepper (*Capsicum annuum,* L), mango (*Mangiferia indica,* L), banana *(Musa* spp), sugar cane (*Saccharum officinarum,* L).

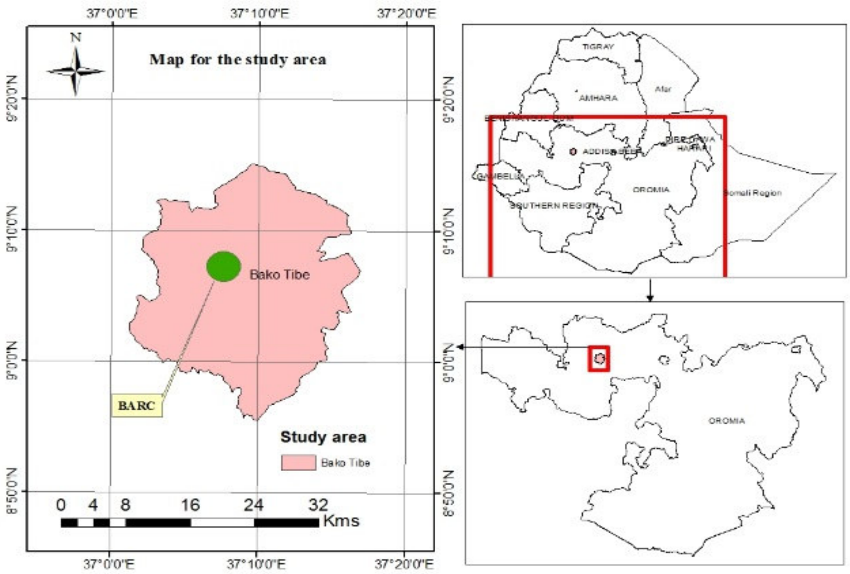

Figure 2. Location map of the study area

2.2. Experimental plots design

The experiment was conducted on run off plots each of having a dimension of 3m wide by 8m long on a slope of about 7% with combination of six treatments; viz. SMCP, SHCP, MHCP, MmCP, MHCA and MmCA. The design adopted for collecting tanks was that of multi-slot divisor in similar way as suggested by (FAO, 1993b; Pathak, *et al*., 1997). Each plot was hydrologically isolated on the surface by corrugated iron sheets installed to a depth of 15 cm and extending 15 cm above the soil surface along the boundaries at the downstream side. The tanks were covered by plastic sheet to prevent entry of direct rainfall and evaporation losses. Precipitation was much more important than the other metrological parameters because rainfall had a direct relation with runoff and sediment generation from experimental plots.

2.3. Data collections and Analysis

2.3.1. Runoff

The measurements for runoff were started immediately after the maize and legume crop were planted and application of maize mulch. Each run off plots had a collecting trough at the extreme down slope position to guide the entire run off from each plot towards the collecting tank. The collecting trough and the plot borders were fixed by mortar to make the junction water tight. Total volume of daily runoff from each plot was measured in the collecting tank after each rainstorm event at 8:00 am. The runoff depth was calculated by dividing the total runoff volume collected in a tank by the plot area. The content of the tank was vigorously stirred with a wooden stick to ensure a uniform distribution of sediment throughout the depth of water in the collecting tank. Immediately after stirring, one litre capacity graduated jar was immersed to a substantial depth beneath the surface of water in the collecting tank and one liter sample of water-sediment mixture was taken in pre-washed 1-L bottles from each collecting tank.

Figure 3. Experimental setup of runoff plots at BARC

2.3.2. Sediment loss

Sediment data were collected from the runoff water samples. The soil sample taken from the runoff was allowed to stand for the suspended load to settle and the clear water was then carefully decanted and the weight of wet sediment per litre of runoff was measured, air dried and kept in oven dried at 105ºC for 24 hours for further physicochemical analysis. The product of the sediment concentration and the total runoff per plot per day was used to determine the daily sediment loss and given by (Heron, 1990; Hudson, 1993).

2.3.3. Enrichment ratio (ER)

Nutrient enrichment ratios (ER) were 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 (Wan and El-Swaify, 1998).

2.4. Data Analysis

To compare the effect of the treatments Separations of significant differences between and among treatment means were done by least significant difference (LSD) test. A simple correlation and regression analysis were done to establish the relationship between rainfall-runoff and runoff-soil loss under all treatments.

3. RESULTS AND DISCUSSIONS

3.1. Rainfall – Runoff Relationships

The rainfall occurred in the experimental site during the main season was for 64 days and the total amount of seasonal precipitation recorded in the study area was 695mm under different soil management practices. The degree of correlation between rainfall-runoff for the cropping season of the study period under different soil management practices is presented in Fig.3 (a)-(f). Out of the total amount of rainfall received 695mm during the experimental season, 80.9% of the seasonal rainfall could have the chance to generate runoff. The long dry period before the onset of summer rainfall affected the start of runoff from agricultural lands for antecedent moisture content and played a great role in runoff generation. The first runoff generated was observed after nineteen days of the planted crop. This is because some amount of water was required to saturate the soil profile. This part of the rainfall was about 6.33% of the total seasonal rainfall received by the area. In this study, antecedent moisture content and roughness conditions were the most important factors in runoff yield. For instance, at saturation a small amount of rainfall 6mm could give runoff on all plots while 10mm of rainfall before saturation did not give runoff on any of experimental plots. These results suggest that rainfall – runoff relationship is a complex, dynamic and nonlinear process, which is affected by many and often inter-related physical factors and this result is in harmony with the research findings reported by (Olkeba *et al*., 2012).

Statistically significant relationships revealed by high value of coefficient of determination (R^2) and correlation coefficient (r) which are derived through regression between rainfall and runoff. The coefficients of determination (R^2), for SMCP was [0.57 (r= 0.64, p< 0.05)], SHCP [0.67 (r=0.73, p<0.05], MHCP [0.75 (r=0.69, p<0.05], MmCP [0.71 (r=0.63, p<0.05], MHCA [0.42 (r=0.68, p<0.05] and MmCA [0.46 (r=0.63, p<0.05]. The relationship between rainfall and runoff is relatively lower in MHCA plot and it might be the reason that much proportion of rainfall is absorbed by intercropping of maize with haricot bean under conservation tillage practices.

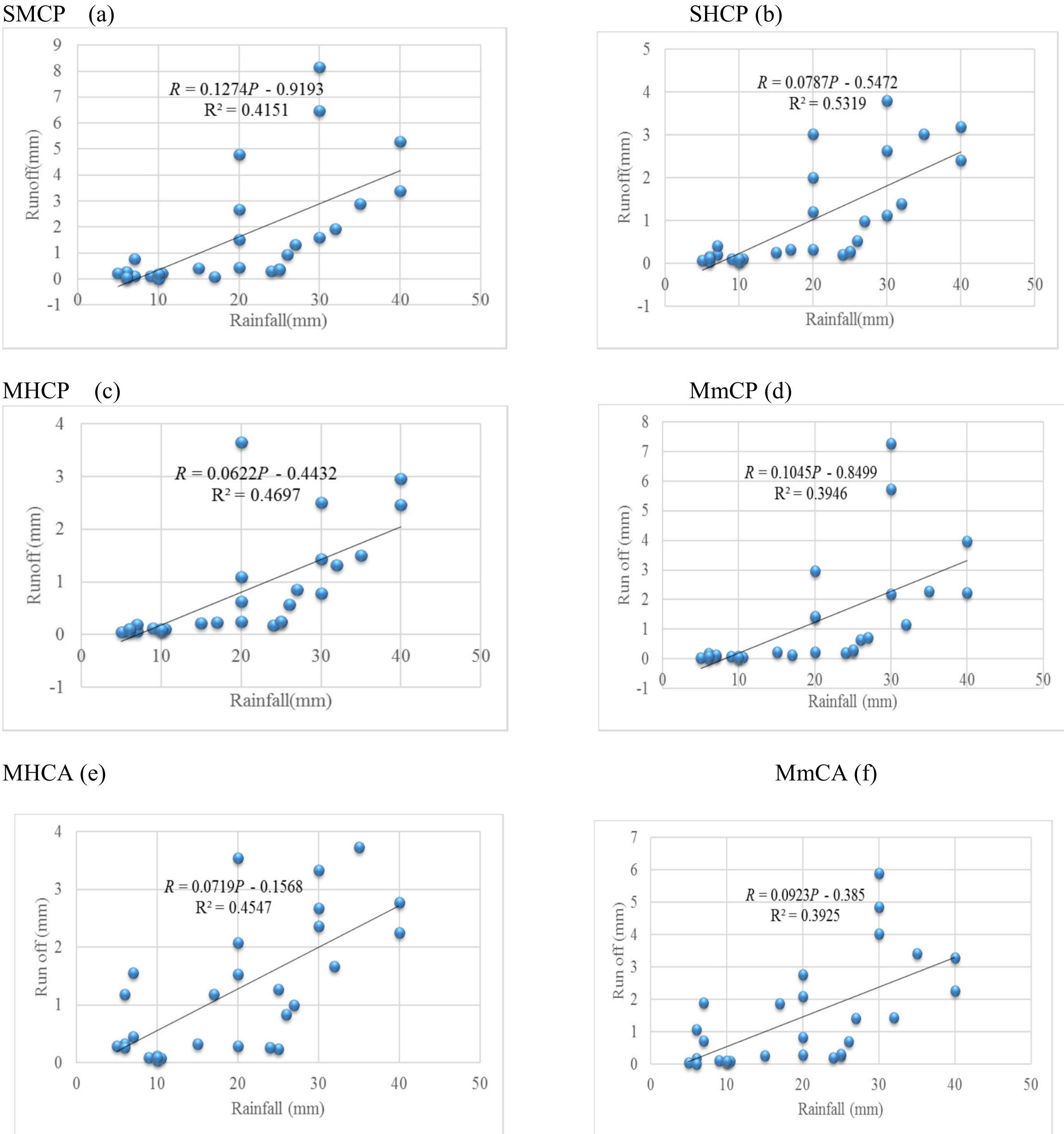

Figure 4. Relationship between Rainfall vs Runoff under different soil management practices

3.2. Runoff –Soil Loss Relationships

Less correlation was noted between rainfall, ***P*** in (mm) and seasonal soil loss, S_L in (t ha^{-1}) values. The soil loss values, therefore, plotted against the runoff, ***R*** in (mm) values. It was observed significant correlation exists between corresponding values of S_L and R as shown in (Fig. (4) (a) - (f)). This might indicates the process of sheet erosion is more dominant in this area as compared to splash erosion. The correlation coefficient (r) provides a good estimate of the overall fit of the regression model. Its large value indicates a strong relationship. The coefficients of determination (R^2), for SMCP was [0.86 (r= 0.92, p< 0.05)], SHCP [0.42 (r=0.64, p<0.05], MHCP [0.49 (r=0.70, p<0.05], MmCP [0.42 (r=0.65, p<0.05], MHCA [0.087 (r=0.73, p<0.05] and MmCA [0.89 (r=0.94, p<0.05]. Under all treatments, runoff and soil loss were positively and highly significantly correlated with rainfall on event basis. Relatively medium value of R^2 associated with these relations may be noted. The plot SMCP is found to have large values of soil erosion. There was, however, a significant difference in runoff responses under different soil management practices (Table 1). The results further revealed that conventional tillage practices was less effective in reducing runoff as compared to conservation tillage practices. Runoff reduction by conservation tillage as compared to the control was 25.39 and 10.37% for MHCA and MmCA respectively (Table 1). The crop residue cover and infiltration rates associated with conservation tillage maximize the volume reduction of agricultural runoff and contaminants and the result is in harmony with the research findings reported by (Evans *et al.,*2000).

Though conventional tillage generated more runoff as compared to conservation tillage, they are better even within the same tillage system as compared to the control and the runoff reduction were observed as 53, 99.4 and 31.81% for SHCP, MHCP and MmCP, respectively and this might be due to intercropping and mulching effect of the treatments. While comparing the mulch applied tillage practices, the treatment containing MmCP is better in runoff reduction as compared with MmCA. This is because of the reduced surface storage capacity of the latter tillage, since the soil surface was relatively smooth as opposed to the traditional systems where surface roughness is created through tillage operations, which form micro depressions in which the excess water is detained. Treatments that received straw mulch with both conventional and conservational tillage reduced soil loss and sediment concentration in runoff. Soil loss reduction as compared to the control was 97.9 and 92.27% for MmCA and MmCP, respectively. This might be attributed to high sediment trapping capacity of the straw mulch. Generally, runoff decreased on all treatments of intercropped and mulch applied plots than control plot. This result is in a consonance with; the research result findings of (Dilshad *et al.,* 1996). But when all the treatments were compared except the control, by far, low runoff volume was recorded from MHCP plots than the others. Less runoff generation from the plots of MHCP management practices during heavy storms might be due to better cover factors and thereby surface infiltration.

Table 2. Mean values of runoff, sediment load in runoff and soil loss as influenced by different soil management under maize-legume production system practices in the experimental plots

Treatments	Runoff depth (mm)	Sediment concentration (g/l)	Soil loss (t/ha)
SMCP	44.99a	66.7a	18.92a
SHCP	28.39cd	45.17ab	7.03bc
MHCP	22.12d	38.23ab	4.69bc
MmCP	34.13cb	62.63a	9.84b
MHCA	35.88cb	27.8b	4.04c
MmCA	40.76ab	48.57ab	9.56b
Mean	34.38	48.183	9.01
CV (%)	13.95	3.772	33.37
LSD(0.05)	8.729	33.066	5.47

N.B:- values followed by a different superscript letters (a, b, c and d) are significantly different across management practice

Table 3. Some nutrients as affected by different soil management practices during the active growing season of the crops

Treatment	P_{av} (kg/ha)	K_{av} (kg/ha)	OC(kg/ha)	TN(kg/ha)
SMCP	0.17 ± 0.02^{a}	12.45 ± 0.55^{a}	367.75 ± 50.89^{a}	33.54 ± 3.67^{a}
SHCP	0.06 ± 0.01^{dbc}	4.82 ± 0.64^{dbc}	137.57 ± 21.64^{b}	12.58 ± 2.02^{bc}
MHCP	0.04 ± 0.01^{dc}	2.95 ± 0.43^{dc}	96.47 ± 10.73^{b}	8.87 ± 1.03^{bc}
MmCP	0.09 ± 0.03^{bc}	5.83 ± 2.44^{b}	191.30 ± 47.23^{b}	17.81 ± 4.36^{b}
MHCA	0.03 ± 0.01^{d}	2.66 ± 0.09^{d}	82.72 ± 4.96^{b}	7.55 ± 0.37^{c}
MmCA	0.10 ± 0.019^{b}	6.56 ± 1.31^{bc}	180.81 ± 52.45^{b}	16.42 ± 3.67^{bc}
CV (%)	**33.69**	**27.37**	**37.09**	**31.84**
LSD (5%)	**0.05**	**3.42**	**118.96**	**9.34**

OC=Organic carbon, TN= Total nitrogen, Pav= Available phosphorous and Kav= Available potassium

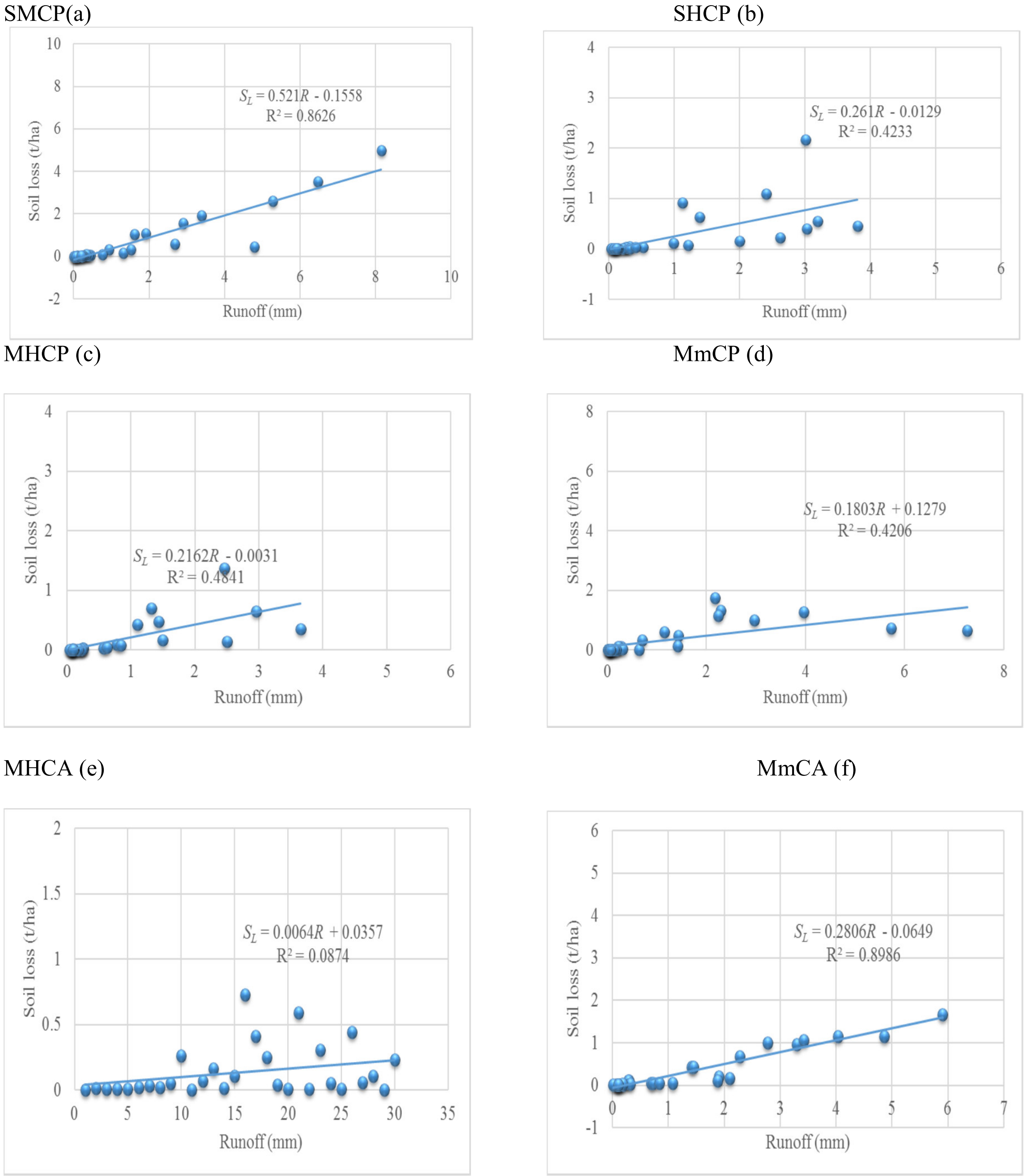

Figure 5. Relationship between Runoff vs Soil loss under different soil management practices

3.3. Nutrient loss as affected by different soil management systems

The loss of nutrients and organic carbon were in the range of 82.719 to 368.747 kg/ ha for OC, for total N 7.550 to 33.538 kg/ ha, available P, 0.039 to 0.179 kg/ ha and 3.230 to 14.230 kg/ha for available K. The results showed that MHCP, SHCP, MmCP, MHCA and MmCA can control the runoff by the order of 50.83, 36.89, 24.13, 20.25 and 9.40% in comparison to SMCP. While Soil loss reduction of the treatments was achieved by the order of MHCA, MHCP, SHCP, MmCA and MmCP as 78.64, 75.21, 62.84, 49.47 and 47.99%. MHCA has higher reduction potential of nutrients for P, K, OC and TN as 78.41, 77.30, 77.57 and 77.49% respectively as compared with SMCP of farmer practices. This result is in agreement with the research findings of in the existing slope and rainfall conditions as reported by Sersu (2000).

3.4. Enrichment Ratio (ER)

The enrichment ratios (ER) of the OC, TN, P_{av} and K are given in (Fig. 5). If the ER of a nutrient is higher than 1, the eroded sediment is enriched in that nutrient. Accordingly, it was noted ER values decreases towards 1 for OC and P_{av} at CA practices as compared to SHCP which has the highest value. Therefore, the results of these experiments indicate that preferential sediment and nutrient transport caused by rill and interrill erosion, is limited. As reported by Wan and El-Swaify (1998) soil material eroded furthest has highest quality, while soil remaining in the field deteriorates faster because remaining soil gets progressively less fertile. The results of these experiment is in agreement with the results of the research findings of (Sharpley, 1985; Proffitt *et al*., 1991).

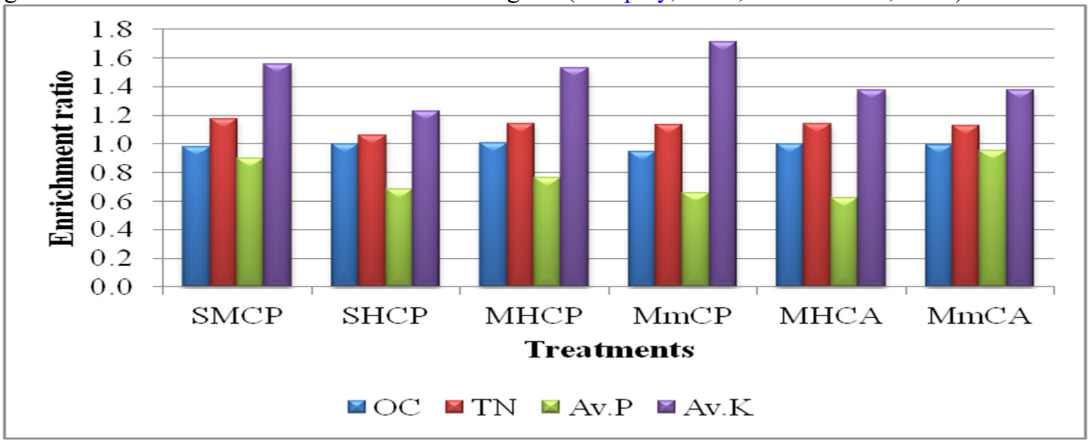

Figure 6. Nutrient Enrichment ratio as influenced by erosive rains under different soil management practices

4. CONCLUSION

Concurrent data on monthly rainfall, runoff, soil loss and nutrient loss have been observed from six experimental plots having different soil management practices at Bako, West Shoa, Ethiopia. The results revealed that there was a significant difference between the treatments regarding their effect on runoff depth, soil loss and sediment associated nutrient losses. The variation of monthly values of rainfall, runoff, soil loss and nutrient loss from the different soil management is also quantified by proposing empirical relationships for their determination. The finding of this study will aid in estimation of the soil, water and nutrient conservation potential of different soil management and recommendation of the necessary bioengineering measures for better management of agricultural soil management practices.

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