CHAPTER 6

ROLE OF MULCHING ON RUNOFF AND SOIL LOSS IN FIELD PLOTS UNDER NATURAL RAINFALL

6.1 Introduction

The importance of protecting the soil surface from rainfall to preserve beneficial soil properties and thereby reduce erosion has long been recognized (Mannering and Meyer, 1962). Surface application of crop residue has proven to be very efficient in controlling soil loss and runoff from agricultural soils (Lal, 1976; Cogo et al., 1983; Roth et al., 1988). Larson et al. (1978) also indicated that proper use of crop residue is one of the most effective tools to solve soil erosion problems.

Crop residues may be used exclusively on the soil surface as a soil cover, or it may be partially mixed with the soil (Kohnke and Bertrand, 1959). As a cover, it is more effective in protecting the soil from the direct impact of the raindrops thereby reducing soil detachment, surface sealing and subsequently runoff and erosion. However, according to the literature, partial mixing of the residue with the soil surface promotes decomposition and results in improvement of soil aggregation and aggregate stability thereby making the soil more resistant to detachment. This effect may however be different under different climatic conditions. It can be assumed that under hot climatic conditions this would be less effective than under cooler conditions due to faster rate of mineralization of organic matter in the former (Grisi et al., 1998; Franzluebbers et al., 2001).

Most of the mulching studies have been conducted under laboratory rainfall simulations on small erosion pans (Lattanzi et al., 1974; Singer and Blackard, 1978; Savabi and Stott, 1994; Cruse et al., 2001; Idowu et al., 2001). The effect of mulching on infiltration, runoff and erosion may be different in magnitude under laboratory and field conditions. In the laboratory experiments, simulated rainfall is usually applied on small erosion plots and runoff occurs mainly when the infiltration capacity is sufficiently reduced and soil loss is mainly due to detachment by raindrop impact.

However, under the actual field conditions, overland flows coming from various interrill areas merge together to form channels and flow in higher concentrations and velocities depending on the gradient thereby contributing to increased runoff and subsequent soil loss. Therefore, under field conditions soil loss is not only a function of detachment by raindrop impact but also due to detachment by concentrated flow due to increased slope length.

Moreover, the percent surface cover provided by a given rate of crop residue is likely to vary when applied to laboratory erosion pans and field plots. Unlike the commonly uniform and levelled soil surfaces in the laboratory experiments, a rough soil surface that results from clods and various depressions under the cultivated field conditions, may reduce the uniformity of the residue cover leaving some spots exposed to the impact of raindrops.

Straw is conventionally spread on the soil surface or incorporated in to the soil at a rate equivalent to yield (average 4Mg ha^{-1}) (Edwards et al., 1995). Reports also indicate that increased mulching rates are expected to produce correspondingly less soil erosion (McGregor et al., 1988). On the other hand, using barely straw in a laboratory rainfall simulation study on fine sandy loam soils, Edwards et al. (1995) reported that there is no advantage in sediment control above a mulching rate of 4t/ha straw. However, the effectiveness of mulching is a function of many factors including rainfall erosivity, soil types and condition, steepness and length of slope and the type and rate of mulch applied (Foster et al., 1982; Poesen and Lavee, 1991). Hence, the need was felt to assess the effect of increased residue rates for greater erosion control and to examine the effects of surface and incorporated patterns of residue application on soil erosion control.

The aim of this experiment was therefore to assess the effectiveness of different rates and application methods of wheat residues in controlling runoff and erosion from large field runoff plots under natural rainfall.

6.2 Materials and methods

The study was conducted at the experimental field of Alemaya University, Ethiopia, during the 2002 rainfall season. The geographical location of the site is 09°26'N and 42°02'E with an altitude of 2000m. The mean annual rainfall for the last 22 years was 845mm. Dominant crops in the area include sorghum, maize, and wheat. Chat (*Catha edulis*) is also commonly grown in the area. The soil at the experimental site is a reddish brown regosol with a sandy clay loam texture underlain by granites. Some physical and chemical properties of the soils are presented in Table 6.1.

Table 6.1 Some physical and chemical properties of Alemaya Regosols

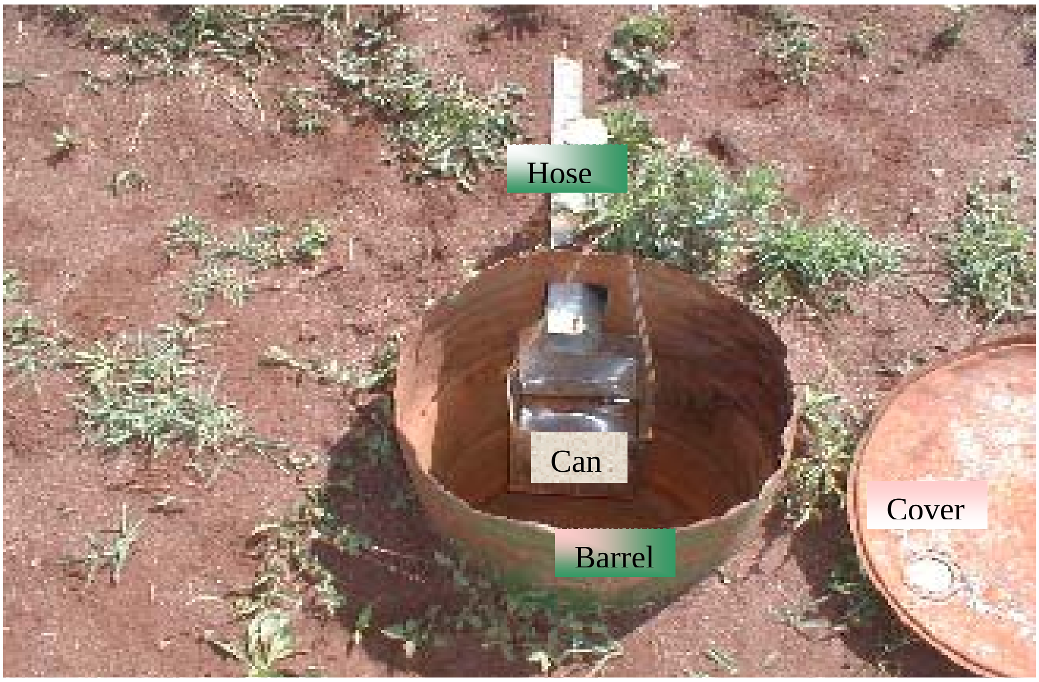
Soil texture %			OC %	BD Mgm^{-3}	WSA %	pH H_2O	CEC	Exchangeable bases ....cmolc kg^{-1}..............				ESP
Sand	Silt	Clay						K	Na	Ca	Mg	
53.1	19.5	27.4	1.62	1.31	66.18	6.55	26.96	0.92	1.11	20.05	4.83	4.12

OC= Organic carbon; BD= Bulk Density; WSA= Water stable aggregates; ESP= Exchangeable sodium percentage

The experimental plots were constructed on cultivated lands with slope gradients of about 8 -10% before the onset of the rainfall season. Runoff plots of 10m long X 2m wide were bordered by corrugated iron sheets which were inserted into the soil to a depth of 20 cm leaving 25 cm above the soil surface to prevent lateral flows from the plots to the adjacent area. The layout of the runoff plots is shown in Fig. 6.1A.

The plots were ploughed manually to a depth of approximately 15 cm with inverted hoes locally called 'Akafa' before straw application. Then, the wheat straw with a soil water content of 8% was applied uniformly on the soil surface and was either left on the surface or incorporated into the soil at rates of 0, 4 and 8 Mg ha^{-1} with three replications making a total of 15 erosion plots. Percent surface cover by the straw was estimated using grid sieves of 8 mm mesh. A 10 x 10 grid mesh was counted and marked on the sieve. By randomly putting the sieve on the mulched surface, the number of openings of the sieves that were covered by the straws was counted and these were considered to represent the percent cover.

A. Experimental setup of the runoff plots



B. Runoff collectors

Fig. 6.1 Illustrations of (A) experimental layout of the runoff plots and (B) accessories for runoff collection

Table 6.2 Percent surface cover by the wheat straw applied at two rates and patterns

Residue rate (Mg ha^{-1})	Residue application methods	Mean percent cover ‡
0	-	0
4	Incorporated	41 (16.15)
8	Incorporated	66 (18.23)
4	Surface	68 (16.61)
8	Surface	88 (11.59)

‡The percent cover values presented here are means of 30 measurements each. Values in the parenthesis indicate standard deviations.

Runoff and sediment loss were collected in a barrel that was buried in the ground at a distance of about one metre from the lower end of each erosion plot. Each erosion plot was connected to a barrel through a hose of iron sheet. A cubic can having a diameter of 20 cm. was hanged in the barrel to collect runoff and sediments of small volumes (Fig. 6.1B). Run off in excess of the cans were collected in the barrel. The top of the barrel was closed securely to prevent entrance of direct rainfall and any other sediments to make sure that whatever is collected in the barrel comes only from the erosion plots.

Runoff was measured from the runoff-collection cans and barrels after each rainfall event. A rainfall in this study refers to that event which initiated runoff at least on the control plots. After thoroughly mixing the contents of the runoff collectors, a known volume of the effluent was oven dried to determine the weight of sediment. The runoff collecting cans and barrels were emptied and cleaned after each measurement to make them ready for the rainfall event.

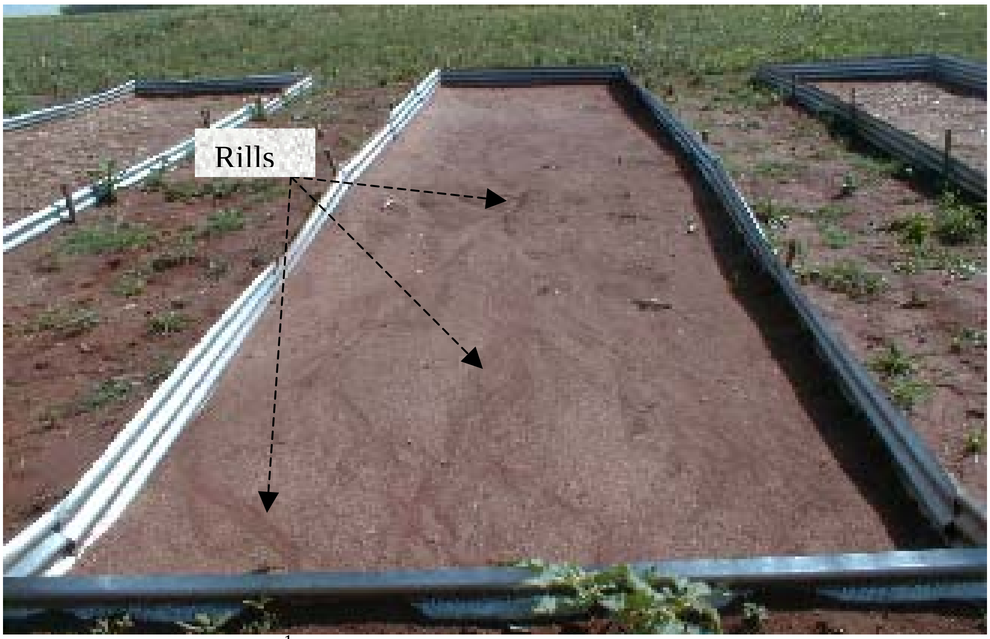
The experimental data were analyzed as randomized block design with three replications using SAS computer software. The significance level used in this text is p=0.05 unless and otherwise stated. The main limitation of this study was that the data were collected for only one season due to lack of funds and time.

6.3 Results and discussion

6.3.1 Runoff

The total runoff for the different treatments that was collected during the experimental period is presented in Fig. 6.3. The result indicated that the mean runoff collected at the control plot (without residue) was significantly higher than those from all residue treated plots ($p<0.001$). A remarkable visual evidence of higher runoff on the control plots was development of rills (Fig. 6.2A), which were not observed on the mulched plots (Fig. 6.2B).

Regression lines were constructed to show the relationship between runoff and mulching rates. The best-fit equations for the surface applied and incorporated residues are exponential with coefficients of determinations of 0.98 and 0.93 respectively. However, the regression equations shown in Fig 6.3 don't give realistic values for the surface and incorporated residue application methods at low mulching rates. Surface application of wheat residue reduced runoff significantly as compared to the same amount of residue incorporated into the soil ($p<0.01$). For a given residue application pattern, runoff was significantly lower on plots that received 8Mg ha^{-1} wheat residue than 4 Mg ha^{-1} ($p<0.01$). However, the difference between surface application of 4 Mg ha^{-1} and incorporation of 8 Mg ha^{-1} was not significant. This can be attributed to the percentage surface cover of the residue. Regardless of the amount of the residue applied, the percentage surface cover by wheat residue rates of 4Mgha^{-1} (surface) and 8 Mg ha^{-1} (incorporated) were 68 and 66 % respectively, and are comparable (Table 6.2). The percentage reductions in runoff due to surface application of 4 Mg ha^{-1} and incorporation of 8 Mg ha^{-1} were 68 and 69% respectively as compared to the control (Table 6.3). Surface application of 8 Mg ha^{-1} wheat residue reduced runoff by 95% as compared to the control plot.



A. Control (0 $Mgha^{-1}$straw)

B. 8 $Mgha^{-1}$ wheat straw applied on the surface

Fig. 6.2 Picture illustrating development of runoff pathways (rills) on the control (no straw) plot A, and absence of this on the residue treated plot, B.

The amount of rainfall collected during the experimental season of the year was 295.1mm. This refers only to the sum of rainfall that induced runoff. The total runoff during the experimental season was 28.03% of the total rainfall at the control plots (bare soils) and 17.4 to 1.4% for the mulched plots. These runoff data were highly correlated (r = 0.87) with the data obtained under laboratory rainfall simulation at 60 mm hr^{-1} intensity. The smaller correlation coefficient than what is normally expected is attributed to the absence of runoff from surface mulched plots (at both 4 and 8 Mg ha^{-1} straw) in the laboratory trials which can be associated to the short slope lengths of the laboratory erosion trays. The correlation between the lab and field results is even lower (r=0.83) when the simulated rainfall intensity is 30 mm hr^{-1} because no runoff was collected from all mulched plots in the lab at this intensity. Despite all these, the laboratory rainfall simulation results can be used as useful guides to compare the effect of various treatments on runoff and soil loss. Use of higher rainfall intensities could offer better results to clearly observe the effects of various treatments under small laboratory plots.

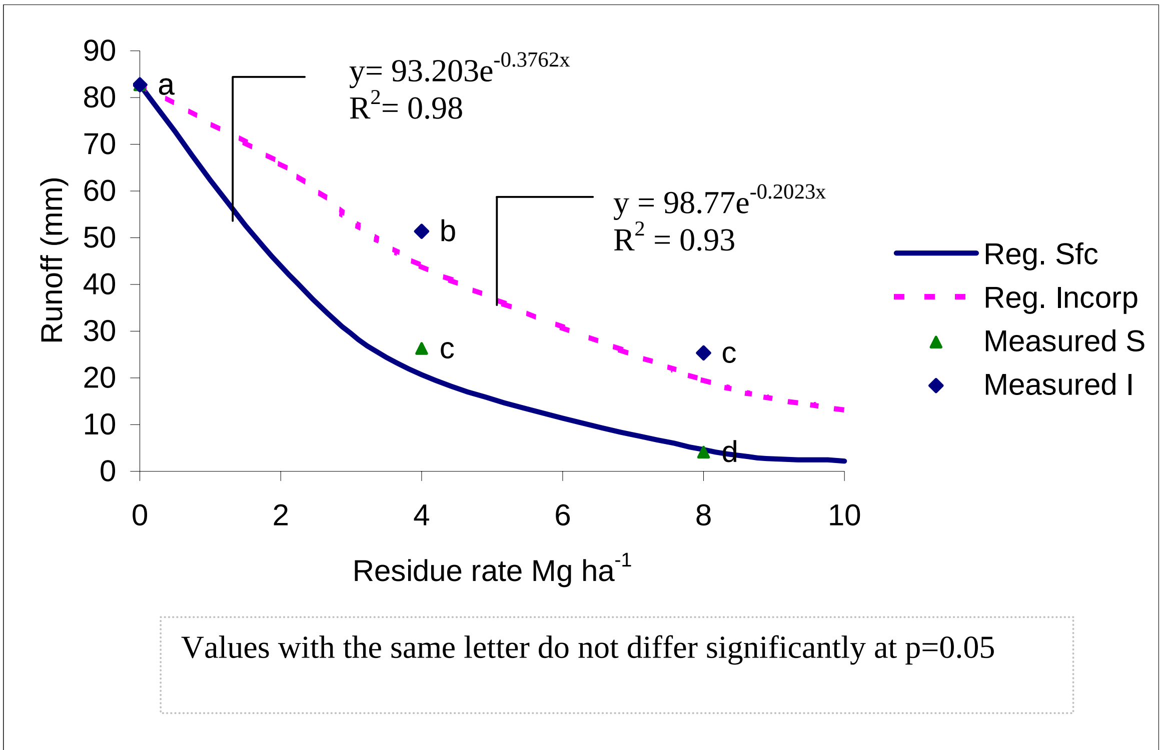


Fig. 6.3 Total runoff (mm) collected during the 2002 rainfall season from the field runoff plots at Alemaya University experimental field station.

Table 6.3 Reductions (%) in runoff due to mulching as compared to the control.

Residue rate	Application method	
	Surface	Incorporated
0	0	0
4	68.2	37.9
8	95.1	69.4

6.3.2 Soil loss

The total soil loss collected from the experimental plots during the entire rainfall season is presented in Fig. 6.4. The result indicated that all crop residue rates and application methods that were considered in the study reduced soil loss significantly as compared to the control plot. The relationship between mulching treatments and soil loss was shown with exponential best-fit equations with coefficient of determinations of 0.99 and 0.97 for the surface and incorporated methods of applications respectively. However, the regression equations given in Fig. 6.4 do not provide realistic results when the residue rates are less than one Mg ha^{-1}.

Because of the financial and time constraints in this experiment, there are only few data points that are not reliable to develop dependable regression equations. Despite that, the equations may still be used to provide estimates the values of soil loss for a certain rate and method of straw application in the absence of a comprehensive data.

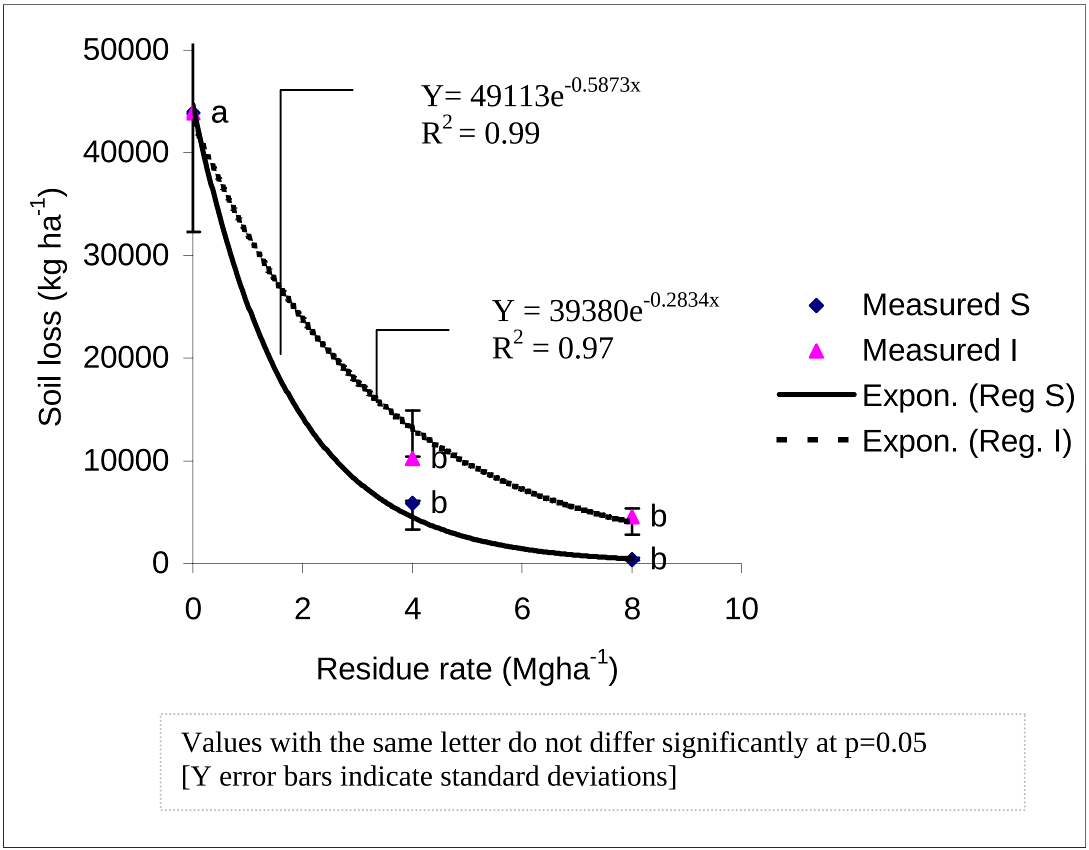


Fig. 6.4 Total soil loss (kg ha^{-1}) collected during the 2002 rainfall season from the field runoff plots at Alemaya University experimental station.

The surface applied mulch at a rate of 4 and 8 Mg ha^{-1} is 42 and 92% more effective respectively in controlling soil loss than the same amount of incorporated mulch. From the residue treated plots, the highest and lowest soil loss reduction as compared to the control were 99.1% and 76.7% which were obtained by surface application of 8 Mg ha^{-1} and incorporation of 4 Mg ha^{-1} wheat residue respectively (Table 6.4). However, the difference between soil losses from the residue treated plots was not statistically significant. This indicates that under the conditions specified for the study site, mulching at a rate of 4 Mg ha^{-1} can effectively control soil loss regardless of the method of application. Therefore, application of more residue rates for erosion control may not be required unless especial cases are envisaged. This result is in agreement with that of Edwards et al. (1995) who studied the effect of barely straw under rainfall simulation at various slope gradients (5, 7 and 9%) on fine sandy loams in Canada.

Table 6.4 Reduction (%) in soil loss at residue treated plots as compared to the control.

Residue rate (Mg ha^{-1})	Methods of application	
	Surface	Incorporated
0	0	0
4	86.6	76.7
8	99.1	89.6

Comparison of the percentage effectiveness of the various rates and methods of mulching on reducing runoff and soil loss reveals that mulching is more effective in controlling soil loss than runoff. This is attributed to reduction in raindrop impact energy by mulching that reduces detachment of soil particles resulting in less sediment availability in overland flow. Moreover, the residues can gradually filter the sediments out of the running water thereby reducing the sediment concentration in the runoff in addition to reducing the runoff speed.

According to the best-fit equations shown in Fig. 6.4, surface application and incorporation of wheat straw at rates less than 1.5 and 2.2Mg ha^{-1} respectively may reduce soil loss by 50% as compared to the control. However, surface application of at least 4 Mg ha^{-1} is required to reduce soil loss to a tolerable level assuming tolerable soil loss of 3t ha^{-1} for the study site. Based on the average wheat grain yield production of 1.1t ha^{-1} and 2.8t ha^{-1} for traditional farming and improved technology packages respectively (Belay, 1997 as quoted by Sertsu, 2000), and assuming a residue: grain yield ratio of 1.5 for most cereals (Lal, 1995) the residue production rate will range from 1.65t ha^{-1} to 4.2t ha^{-1}. According to the regression equations presented in Fig 6.4, surface application of the residue obtained by conventional farming (i.e. 1.65 t ha^{-1}) may reduce soil loss at least by 50%. This result also suggests that for conditions similar to the study sites, the residues produced through application of improved technological packages will be adequate to reduce soil loss to tolerable level provided that all are left on the soil surface. However, as this information is based on only one season data, it should be confirmed by further research for lower residue rates and different agro climatic conditions.

6.3.3 Runoff and soil loss at each rainfall event

Runoff and soil loss followed similar patterns to the rainfall at the study site (Fig. 6.5). During the first part of the rainfall season, few erosive rainfalls were recorded till 18 June 2002. These rainfalls were high enough to induce erosion on most of the erosion plots. Therefore, even if the rainfall and erosion during the first part of the rainfall season look smaller than the that of the second part of the season at the experimental plots, an appreciable soil loss usually occurs during this first part of the rainfall season on cultivated farmlands due to various agricultural activities including soil cultivation and vegetation clearance during land preparation that expose the soil surface to the raindrop impact as compared to the second rainfall season where most of the crops are at good stand to provide the maximum surface cover.

No erosive rainfall occurred between 19 June and 24 July. As shown in Fig 6.5, maximum erosion was recorded from the experimental plots in August and September due to the high rainfall pattern. The effectiveness of the mulching (crop residues) in reducing runoff and soil loss was also reduced with increasing rainfall with time. Visual inspection of the experimental plots during the study period revealed that gradual redistribution of the straw within the plots and its loss with time made the soil surface more exposed to the impacts of rainfall energy. The other reason could be due to the high frequency rainfall that usually falls on already saturated surfaces that results in early initiation and higher volume of runoff, which may even carry the straws thereby reducing the effective surface cover.

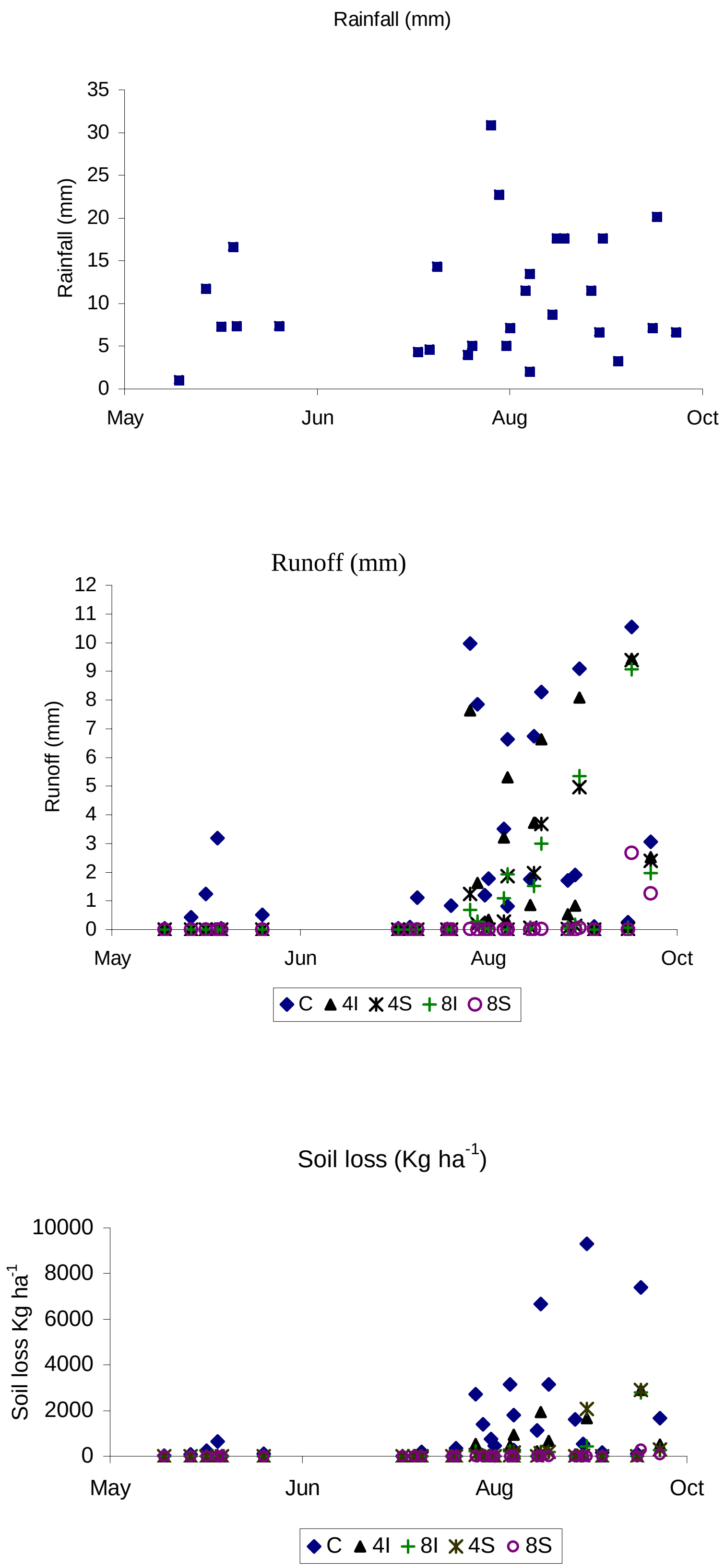


Fig. 6.5 Erosive rainfall (mm), runoff (mm) and soil loss(kg ha^{-1}) during the 2002 rainfall events at Alemaya erosion plots.

6.3.4 Trends of runoff and soil loss with cumulative rainfall

The relationship between cumulative rainfall and cumulative runoff and soil loss during the rainfall season is presented in Fig. 6.6. Runoff did not occur on residue treated plots during the first rainfall events that fell when the soil profile was dry. Successive rainfall initiated runoff later when the soil profile became wetter and due to surface sealing resulting from raindrop impacts. Higher runoff at the later stages of the rainfall season was associated with reduction in the matric potential of the soil due to the saturation of pore spaces with water and surface sealing during the first rainfall events. The fact that runoff was delayed on the residue treated plots as compared to the control (Fig.6.6A) is due to reduction in surface sealing and increased infiltration on mulched surfaces owing to reduced raindrop impact energy and increased surface roughness provided by the residue. Runoff often follows tortuous paths on the mulched plots, thus decreasing the average flow velocity (Meyer et al., 1970). Sediments are also obstructed and filtered by the crop residue reducing the overall sediment discharge.

This study indicated that surface application of a given rate of wheat residue is more effective in reducing runoff and soil loss as compared to incorporating the same amount to the soil. As shown in Fig. 6.6, Surface application of 4 Mg ha^{-1} wheat straw was as effective as incorporating twice as much wheat straw in reducing runoff. Surface application of 8 Mg ha^{-1} wheat straw effectively protected runoff and soil loss during the entire rainfall season. The fact that the rate of runoff and soil loss increased on the residue treated plots towards the end of the rainfall season could be attributed to the gradual reduction in the residue cover due to removal by overland flow and wind as well as its disintegration through time.

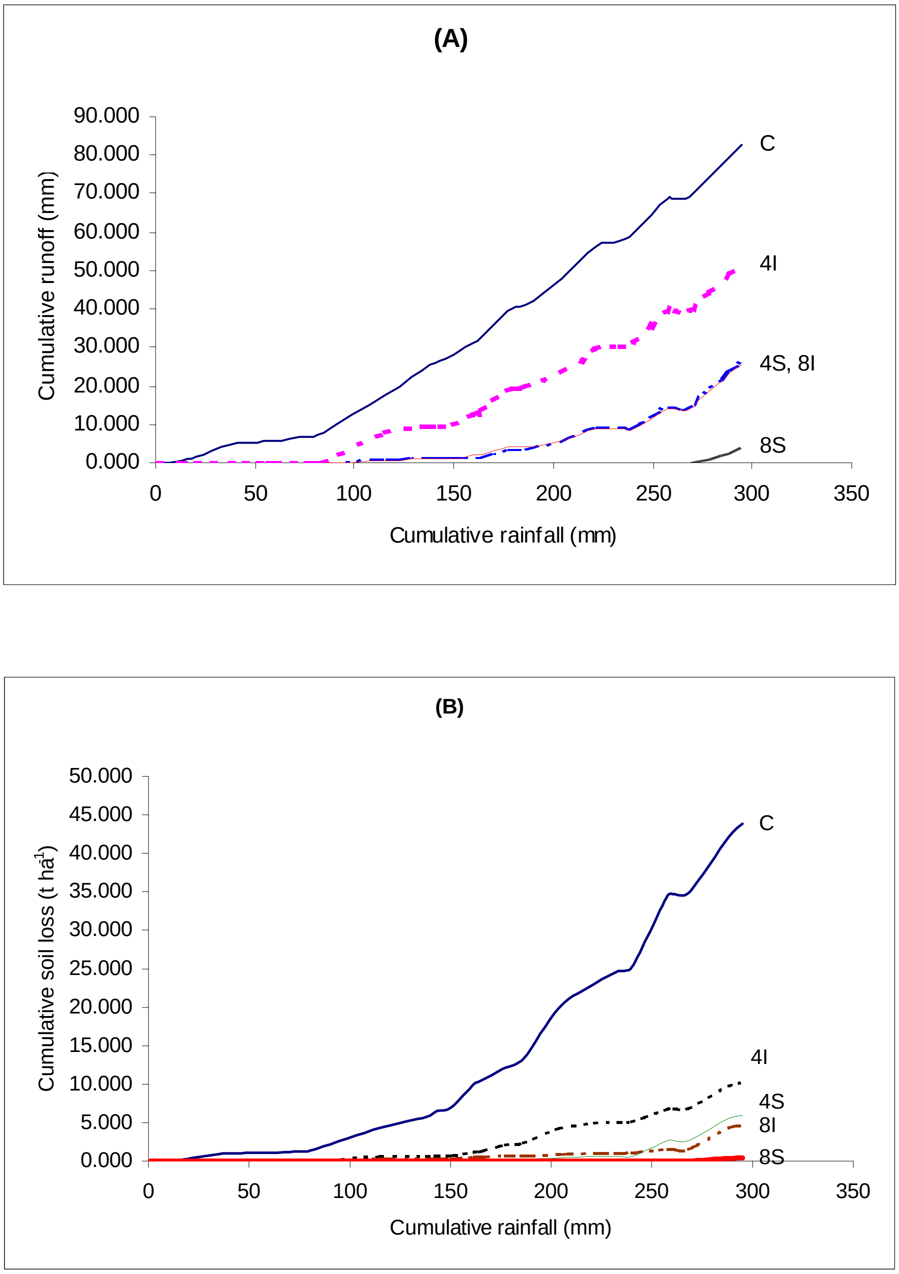


Fig. 6.6 The relationship between cumulative rainfall (mm) and cumulative runoff (mm) (A), and soil loss (kg ha^{-1}) (B) for three rates and two application methods of mulching during the 2002 rainfall season at Alemaya.]

6.4 Comparison of measured and estimated soil losses under mulching treatments

The total soil loss that was recorded from the field runoff plots during the study year was compared with the soil loss values predicted by using the SLEMSA and USLE models and are presented in Fig. 6.7.

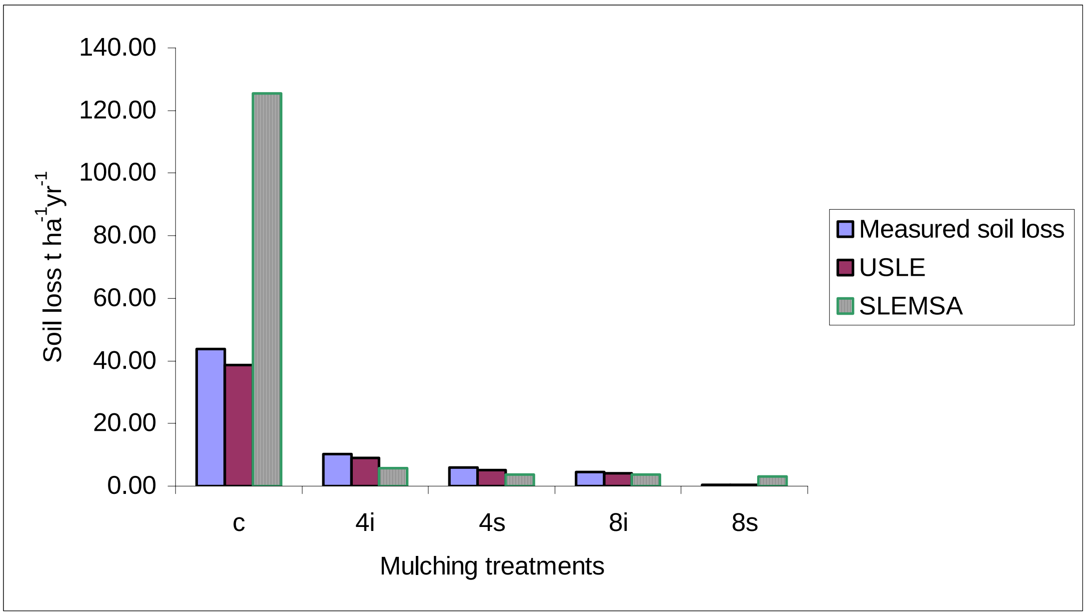


Fig. 6.7 Measured and estimated (by using the USLE and SLEMSA models) soil loss (t ha^{-1} yr^{-1}).

The results indicate that the soil loss values that were estimated by using the USLE were lower than the measured values. These values are however closer to the measured values as compared to those estimated by using SLEMSA. Moreover the USLE was more sensitive to the various percent covers provided by different mulching rates and application methods. On the other hand, SLEMSA overestimated soil loss from the bare soil as compared to the measured soil loss. It however underestimated the soil loss for the mulched plots as compared to the measured values. The differences among soil loss values for the mulched treatments as estimated by using SLEMSA were not well dispersed indicating the less-sensitivity of SLEMSA to change in cover. Although a one-year data is not sufficient to reach at some concluding remarks, the available results suggest that, the USLE is more appropriate for the conditions of this experiment to evaluate the effectiveness of percent mulch cover against soil loss as compared to the SLEMSA model.

6.5 Conclusion

Wheat straw used as mulch at rates of 4 Mg ha^{-1} and 8 Mg ha^{-1} at both application methods (surface and incorporated) significantly controlled runoff and soil loss as compared to the non-mulched plots (control) under field and natural rainfall conditions. Runoff and soil loss were reduced by at least 37 % and 76 % respectively on the residue treated plots as compared to the control. For a given application method, increased residue application rates reduced runoff significantly. Surface application of wheat residue was more effective in controlling runoff than incorporation the same amount into the soil.

Although higher rates and surface applied residue apparently reduced soil loss as compared to lower rates and incorporated ones, the difference among the residue treated plots was not statistically significant. Therefore, under limited availability of residue where it is usually used for different household purposes, 4 Mg ha^{-1} wheat straw can effectively be used to control soil loss for areas having similar topographic and climatic conditions with that of the study site. However, since this figure is still greater than the average residue production rate for most cereals in the country, further research is required to evaluate the effectiveness of lower residue rates on soil conservation.

Comparison of measured and estimated soil losses from mulched plots on Alemaya university regosol revealed that the USLE provided more realistic estimates that are closer to the measured values with greater sensitivity to changes in surface cover as compared to the SLEMSA model.