CHAPTER 5

CHANGES IN SOIL ERODIBILITY UNDER SIMULATED RAINFALL AS INFLUENCED BY MULCHING RATES AND APPLICATION METHODS

5.1 Introduction

Agriculture in developing countries is mainly based on crop production whose main products include grain and straw. The grain is mainly used for human consumption while the crop residue is used for various purposes including for construction of huts, as a source of fuel and fodder (Lal, 1995). Because of these uses, virtually no crop residue is left on the soil surface for soil and water management purposes or is incorporated into the soil to maintain the organic matter content.

On the other hand, many reports indicate the effectiveness of crop residue as a surface cover to protect the soil surface against the impact of raindrop energy (Meyer et al., 1970; Larson et al., 1978) and to improve water infiltration and storage (Lal, 1995). Different reports also indicated that mulching is one of the most cost effective means of crop residue usage (Dickey et al., 1985; Shelton et al., 1995). Moreover, several other related studies (Aarstad and Miller, 1978; Foster et al., 1985; Meyer, 1985; Box and Bruce, 1996; Sharma, 1996; Idowu et al., 2001) indicated that raindrop impact energy is reduced by covering the soil surface with crop residues which consequently reduce surface sealing, increase infiltration and reduce surface runoff and erosion. Lal (1976) demonstrated that soil loss could significantly be reduced with increasing rates of mulch application on a tropical alfisol. Different scientists working under different climates and much different soils have reported reduction in soil loss and runoff due to surface residues, even on very steep slopes (Lal, 1982; Norton et al., 1985).

In most of the studies the effectiveness of crop residue was evaluated by applying a certain rate of the residue on the soil surface. However, under practical field conditions, the residue that is left on the soil surface is usually incorporated into the soil during cultivation to prepare the soil for the next crop thereby reducing its effectiveness as a mulch.

The objectives of this experiment were therefore to

(1) Evaluate the effectiveness of different mulching rates in controlling runoff and erosion on Alemaya regosols of Ethiopia and

(2) Compare the differences in effectiveness between surface application and incorporation of crop residues in controlling runoff, soil loss, and splash detachment under different rainfall intensities.

5.2 Materials and methods

The soil used in this experiment was a sandy clay loam regosol obtained from Alemaya University Experimental Field Station, Ethiopia. Regosols are the most dominant soils in Alemaya district. These soils are dark reddish brown to red in colour and have 53.1% sand, 19.5% silt and 27.4% clay with an organic carbon content of 1.62%. The most common soil forming rocks in the sampling areas include granite and limestone the former being more predominant.

Composite soil samples that represent the entire soils of the area were collected from the top 0.15 m. of the soil surface. Air-dried soils that passed through 4mm sieve were packed into the erosion trays having dimensions of 554 mm-long, 206 mm-wide and 85 mm deep. After packing the soil into the erosion trays, wheat residue was applied at rates of 0, 4, and 8 Mg ha^{-1} either by uniformly spreading over the soil surface or by incorporating it into the soil.

The erosion plot was inclined to 5° slope gradient and was subjected to two rainfall intensities of 30 and 60 mm hr^{-1} for 1 hour. The rain intensity treatments were applied at random to the different mulching treatments. The splashed material was collected from splashguards and troughs mounted at the borders of the plots in such a way that the splashed sediments could be trapped. The sediment was washed into the splash collectors at five minutes during the treatment. The amount of sediment carried by surface flow was also collected and both sources of sediment determined after oven drying the effluent containing the sediments. Runoff volume was also collected at five minutes interval. Unlike the case in other experiments where runoff was considered to be the sum of splash water and surface flow, only the surface flow was taken as runoff in this experiment because of some technical difficulties in the measurement of the splash volume.

Statistical analysis

The experiment consisted of a 3 x 2 x 2 factorial involving three rates and two application patterns of wheat residue and two rainfall intensities. CRD with three replications was used. The experimental data were statistically analysed by using the SAS computer software. Regression analysis was done to assess the relation between percent surface cover of the residue and splash weight. Correlation analysis was also done to assess the relation between the erosion parameters. The level of significance used was $P<0.05$ unless otherwise stated.

5.3 Results and discussion

5.3.1 Runoff

The mean runoff collected from the different erosion trays during the one-hour rainfall simulation is presented in Fig. 5.1. At both 30 and 60mm hr^{-1} rainfall intensities, all residue rates and application methods significantly reduced ($P= 0.0354$; and $P<0.0001$ respectively) runoff compared to the control (no residue).

The results also indicated that surface application of wheat straw at both rates (4 and 8Mg ha^{-1}) reduced runoff under both rainfall intensities. Similarly, incorporation of wheat residue into the soil at both (4 Mg ha^{-1} and 8 Mg ha^{-1}) rates reduced runoff by

92% and 98% respectively as compared to the control. Cruse et al. (2001) reported a similar reduction in the rate of overland flow with increasing residue cover. In a simulated rainfall experiment on small erosion boxes using soybean stem residue as a soil cover, they indicated that residue cover reduced the rate of overland flow by interrupting the flow path thus favouring infiltration and reducing runoff. The work reported by Lattanzi et al. (1974) also indicated that wheat straw mulching at a rate of 8 Mg ha^{-1} drastically reduced runoff from erosion pans as compared to the control plot on Russell silt loam soils that received a simulated rainfall of 64 mm hr^{-1}. Gilley et al. (1986) also supported this finding on a field plot rainfall simulation experiment at an intensity of 28 mm hr^{-1}, conducted on typic Hapludolls of South western Iowa, that addition of increasing amounts of residue up to 13.45t ha-1 reduced runoff significantly. They also indicated that runoff didn't occur on any of the treatments during the initial run.

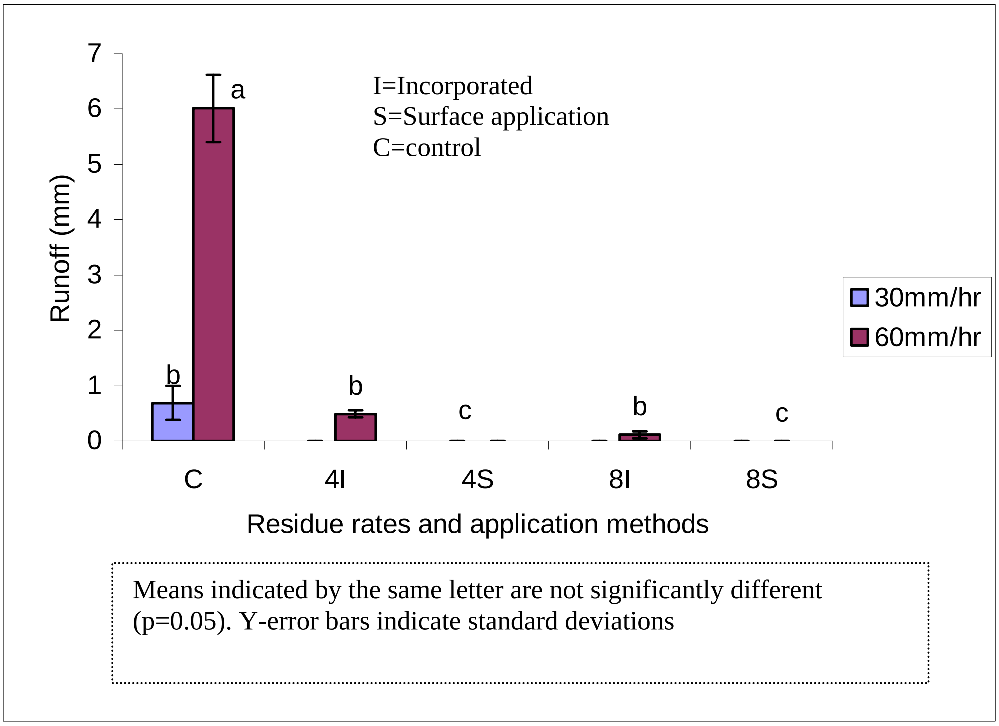


Fig. 5.1 Mean runoff (mm) collected under 30 and 60 mm hr^{-1} intensity of rainfall.

On the other hand, on a field plot (22.1m long x 4m wide) experiment conducted at Charlottetown (Canada), on fine sandy loam under an average annual precipitation of 1097mm, Edwards et al. (2000) reported that runoff was not affected by barely straw mulching at a rate of 4 Mg ha^{-1}. Similar findings were reported on erosion plots of

0.9m long by 0.3m wide of the same soils for surface incorporated straw rates of 2 to 8 Mg ha^{-1} (Edwards et al., 1995).

In spite of the fact that the findings reported in the literature vary much, they all indicate that there were reductions in runoff. Where little or no effects were observed, it was usually due to variations in the soil properties. It could probable be expected that in soils high in organic matter content in the cool areas of the world, less response to mulching could be expected. The results reported here however are for soils that are relatively low in organic matter content and mulching leads to significant reductions in runoff.

The small-scale laboratory results should be supplemented with field scale experiments before making decisions as extrapolation of such data that are obtained from very small erosion plots to field applications can be misleading. This is mainly because, under field conditions, various surface phenomena encourage runoff to flow at higher concentrations and high velocity that can even remove the residue itself. It should be noted that, the fact that this experiment was conducted on fresh wheat straw might have also exaggerated the results. Because, crop residues applied to the field conditions normally disappear with time through decomposition and/or removal by various factors like wind, animals, and overland flow, which will gradually reduce the effectiveness of the residue to control the various erosion parameters.

5.3.2 Sediment yield

The sediment yield followed a similar trend to that of runoff under all treatments. None of the interactions among the rainfall intensities, residue rates and application methods were significant. However, sediment yield was significantly different at 30 and 60mm hr^{-1} (P=0.0038) of rainfall. No sediment yield was observed on residue treated plots at rainfall intensity of 30mm hr^{-1} as there was no runoff. At this rainfall intensity, sediment yield was recorded only on the control plots.

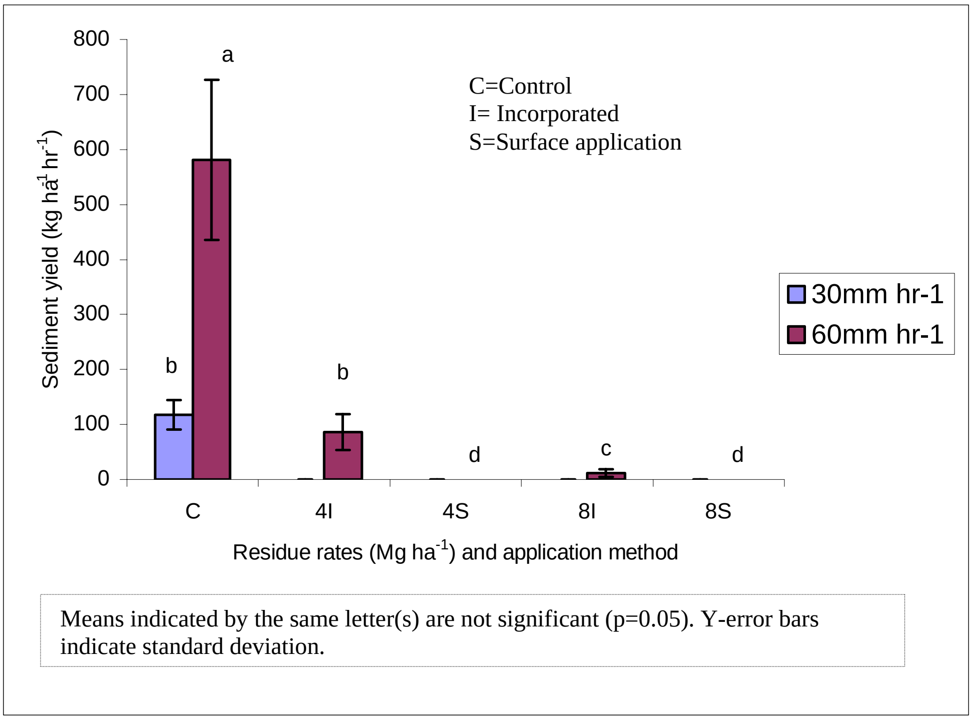


Fig. 5.2 Mean weight of sediment yield (kg ha^{-1} yr^{-1}) collected under 30 and 60 mm hr^{-1} intensity of rainfall.

When the simulated rainfall was applied at 60mm hr^{-1}, some sediment yield was collected on residue-incorporated plots in addition to the control plot. At this rainfall intensity, residue cover has significantly reduced sediment yield as compared to the bare soil. Similar effects of crop residue mulch on sediment yield were reported by several authors (Mannering and Meyer 1962; Singer and Blackard, 1978; Singer et al., 1981; Edwards et al., 1995; Cruse et al., 2001). Among the plots to which wheat straw was applied, the highest sediment yield was recorded on the plot that received wheat straw at a rate of 4 Mg ha^{-1} incorporated into the soil.

At both simulated rainfall intensities, surface application of wheat straw at 4 Mg ha^{-1} and 8 Mg ha^{-1} prevented sediment loss. Besides, incorporation of the residues at rates of 4 and 8 Mg ha^{-1} reduced sediment yield by 85 and 98% respectively as compared to the control at a rainfall intensity of 60mm hr^{-1}. This indicates that application of wheat straw as low as 4 Mg ha^{-1} can sufficiently reduce soil loss resulting from runoff on interrill areas under the conditions specified in this experiment. In Canada, from an experiment conducted soil on cassettes filled with fine sandy loam soils under natural rainfall, no differences in soil loss was reported between plots that received barely residue rates of 4, 6, and 8 Mg ha^{-1} (Edwards et al., 1995) while at a straw rate of 2 Mg ha^{-1}, soil loss was about twice of that obtained under the above residue rates. Therefore, it was suggested that more than 4 Mg ha^{-1} (that is considered as a standard rate), residue rate is not needed to reduce soil loss while less than this amount provides significantly less than the maximum achievable erosion control. Here again, due to the differences in the climatic conditions that would bring about differences in organic matter content, the responses of the Ethiopian soils and those of the cool areas such as Canada to mulching could be different.

5.3.3 Splash detachment of soil

For erosion experiments conducted on small runoff plots (trays) in the laboratory, measurement of splash detachment is more representative to the actual field conditions than runoff and sediment yield; because in both laboratory and field conditions, slope length has little impact on the amount of splashed sediment as opposed to the case of runoff and sediment yield which are significantly affected by slope length and landform.

The mean splash weight as affected by residue rates and application methods is presented in Fig.5.3 for two rainfall intensities. The rates and patterns of wheat residue as well as rainfall intensity showed a significant interaction ($P<0.001$) effect on splash detachment. When rainfall was applied at an intensity of 30mm hr^{-1}, both surface and mixed residue application methods had significantly ($P<0.001$) reduced splash detachment as compared to the control. However, at this same rainfall intensity, splash detachment was not significantly different between surface and mixed patterns of wheat residue applied at a rate of 8 Mg ha^{-1}. Surface application of 4 Mg ha^{-1} wheat straw was significantly better ($P=0.001$) in reducing splash detachment than incorporation of the same amount of this residue into the soil. Though splash weight generally decreased with increase in the rate of crop residue application, between residue application rates of 4 and 8 Mg ha^{-1} for a given pattern of application.

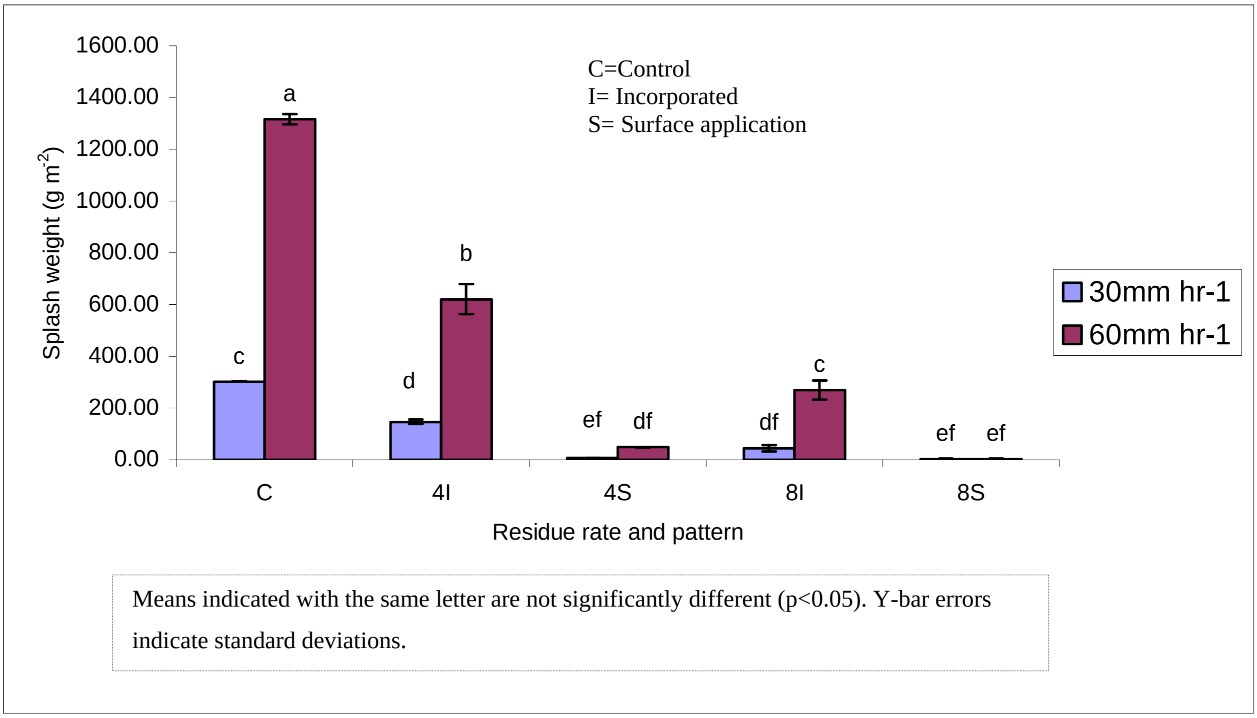


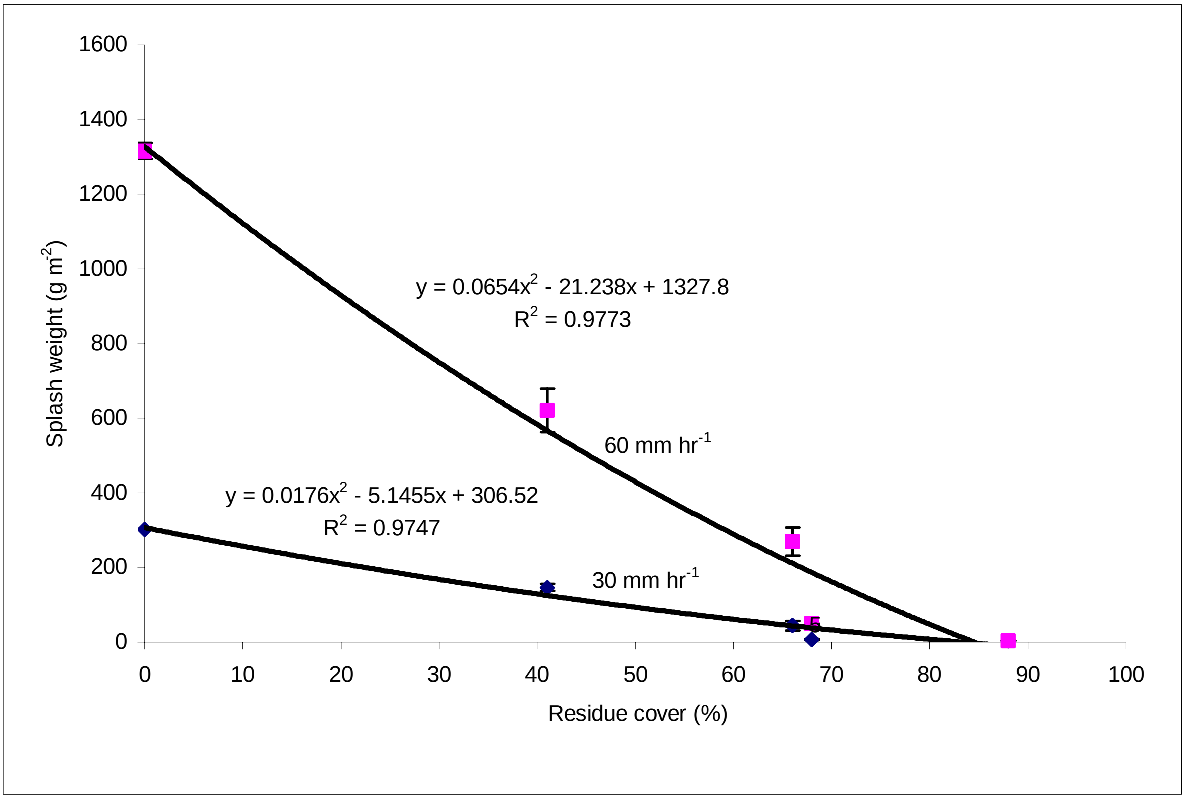
Fig. 5.3 Mean splash weight as affected by wheat residue rates and patterns at rainfall intensities of 30 and 60mm hr^{-1}.

At a rainfall intensity of 60 mm hr^{-1}, incorporation of 8 Mg ha^{-1} wheat residue significantly reduced splash weight as compared to 4 Mg ha^{-1} ($P<0.0001$). However, splash weight didn't differ significantly between surface application of 4 and 8Mg ha^{-1} residue rates because very little splash was recorded. In general splash weight decreased in the order of Control > 4I>8I>4S and 8S at both 30mm hr^{-1} and 60mm hr^{-1} rainfall intensities.

This experiment reveals that, in addition to the amount of crop residue added to the soil, much attention should be given to the method of its application. As indicated before, 4 Mg ha^{-1} wheat straw applied on the soil surface was more effective in controlling splash loss than incorporating even twice as much residue into the soil. This is because more percentage surface cover is obtained when a residue is uniformly spread on the soil surface than when it is incorporated into the soil. In 1954, Osborn (quoted by Singer and Blakard, 1978), using rainfall simulation, showed that percent of the soil surface occupied by cover was the single most effective measure of the effectiveness of cover in reducing splash erosion.

The general trend of splash detachment under various surface covers is presented in Fig.5.4 for 30mm hr^{-1} and 60mm hr^{-1} intensity of simulated rainfall. Splash weight responded more linearly to percentage surface cover than crop residue weight. At both rainfall intensities, splash weight decreased with increase in percent residue cover. Similar inverse relationships between percent residue cover and splash weight had been reported by several researchers (Lattanzi et al., 1974; Singer et al., 1981; Edwards et al., 2000; Cruse et al., 2001).

As shown on Fig 5.4, second- order polynomial curves fit the data points best for both rainfall intensities with coefficient of determination of greater than 0.97. However, the regression equations do not provide a valid estimate of splash weight when the surface cover exceeds 83% for 30mm/hr and 84 % for 60mm/hr rainfall intensity.



Y-error bars indicate standard deviations (g m^{-2})

Fig. 5.4 Splash weight as affected by percent residue cover and rainfall intensity for the 30 and 60 mm hr^{-1} intensity rain shower.

5.3.4 Trend of splash detachment with increasing cumulative rainfall

The trend of splash detachment with increasing cumulative rainfall for rainfall intensity of 30 and 60 mm hr^{-1} is presented in Fig. 5.5. For both rainfall intensities at the control plots, splash detachment increased with increasing cumulative rainfall for the first 25mm of rain and started decreasing thereafter. The rate of increase during the first 25mm of rainfall was higher for 60 mm hr^{-1}. The increase in splash detachment at the first half of the runs and decrease thereafter can be attributed to two main reasons. Firstly, at the beginning of the runs, the soil particles are dry and relatively loose and hence are more susceptible to detachment by the direct raindrop impact. As the soil gets wetter with increased rainfall, particles from the broken aggregates start to fill the pore spaces forming seals that are resistant to the splashing force of the raindrops, and hence reduced availability of the soil particles for detachment. Secondly, with increasing cumulative rainfall, the soil becomes gradually saturated and some ponding of water may occur. This temporary ponding of water on the soil surface may increase the gap between the falling drops and the soil particles and hence, reducing splash detachment.

For the residue treated plots that received rainfall at 30 mm hr^{-1} intensity, splash detachment increased almost linearly with increase in cumulative rainfall especially where the residues were incorporated. For equal rate of residue application, the rate of increase in splash weight was higher for the incorporated residues than those applied on the surface. Surface applications of 4 and 8 Mg ha^{-1} wheat residue have almost protected the soil from raindrop impact during the whole rainfall event.

At a rainfall intensity of 60 mm hr^{-1}, the trend of splash detachment with increasing cumulative rainfall formed a bell-shaped curve on the control plot. The possible reasons for the initial sharp increase in splash weight and gradual decrease latter on, as mentioned earlier are the availability of loose soil particles during the initial runs on one hand, and surface sealing, prevalence of stable aggregates as well as water ponding during the latter stages of the runs. A slight hump on the curve at 25mm rainfall of plots to which wheat residue has been incorporated at a rate of 4 Mg ha^{-1} is also an indication of some exposure of the soil particles to raindrop impact energy making it to show some characteristics of the bare soil.

At higher residue rates, the hump nearly disappears and linear increase in splash weight (if at all) with increase in cumulative rainfall occurs. This gradual increase in splash weight on mulched surfaces could be attributed to gradual redistribution of the residues due to the continued raindrop impact leaving some openings where the soil could be exposed to the direct impact of rainfall.

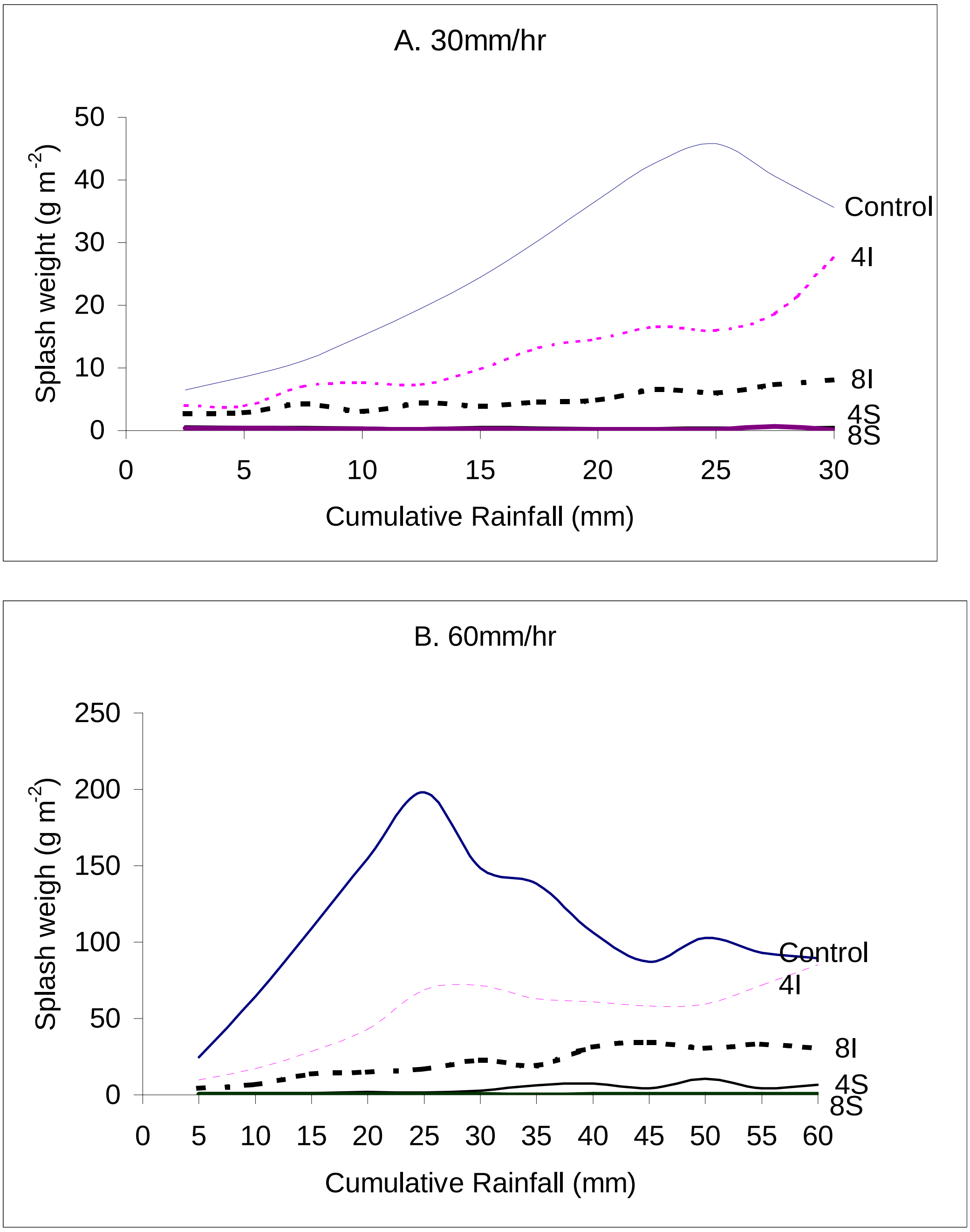


Fig. 5.5 Trends of splash detachment as influenced by rates and application methods of wheat straw under simulated rainfall intensities of (A) 30 mm hr^{-1} and (B) 60 mm hr^{-1}.

5.3.5 Relationships among the erosion parameters

Correlation analysis was performed among the erosion parameters considered in this study to assess the general trend of one erosion parameter versus others. As expected, runoff was highly correlated with sediment yield (r=0.96) and splash weight (r=0.93)

(Table 5.1). The relationship between runoff volume and sediment yield is presented in Fig 5.5. Moreover, sediment yield is also highly correlated with splash weight (r=0.87). These positive linear relationships among the erosion parameters indicate that those treatment combinations that tend to increase runoff have similar effect on sediment yield and splash detachment.

Table 5.1 Correlation coefficients (r) and P values among some erosion parameters measured in the study

	Runoff	*Sediment yield*	*Splash Weight*
Sediment yield	0.96 (P<0.0001)	1	
Splash weight	0.93 (P<0.0001)	0.87 (P<0.0001)	1
Water retention	-0.15 (P=0.3769)	-0.11 (P=0.5297)	-0.14 (P=0.4082)

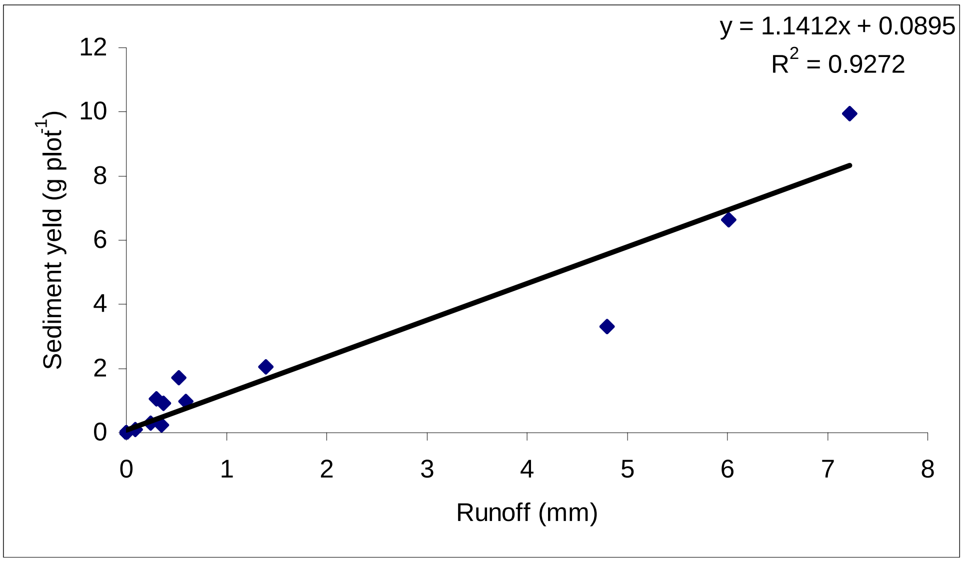


Fig. 5.6 Relationship between runoff and sediment yield under laboratory rainfall simulation.

On the other hand, the amount of water retained by the soil as well as the drainage volume were negatively correlated with runoff, sediment yield and splash detachment though none of these correlations were significant. Those treatment combinations that encouraged high water retention have also induced high drainage. Drainage and water retention showed significant correlations (r=0.63). The fact that high surface cover reduced runoff, sediment yield and splash detachment can be explained by increased infiltration rate of the soil as well as impaired raindrop impact provided by the higher mulch rates.

5.3.6 Comparison of laboratory results with model values

Laboratory based soil erosion experiments usually provide treatment effects for any given time interval within the experimental period. Extrapolation of such laboratory results either in time or space and using such information to evaluate empirical models like SLEMSA and USLE may however lead to erroneous conclusions. Furthermore, both SLEMSA and USLE are not meant for quantifying event-based erosion. Therefore, the cover effect in this small laboratory trial was not compared with the effect of canopy cover in the USLE and SLEMSA models. Such a comparison is however presented for the field trial as indicated in chapter 6.

5.4 Conclusion

Mulching reduced runoff, sediment yield, and splash erosion as compared to the bare soil at both rainfall intensities.For equal rates of wheat residue at a given rainfall intensity, surface application of the straw was more effective in reducing runoff, soil loss and splash detachment as compared to where the residue was mixed with the soil.

Besides, at 60 mm hr^{-1} rainfall intensity, runoff, soil loss and splash detachments were reduced with increased application rate of incorporated wheat residue. The same was true for splash detachment at rainfall intensity of 30 mm hr^{-1} though no runoff and sediment yield were collected at this intensity under any of the residue treated plots.

At a given rate and application method of mulching, application of rainfall at 60 mm hr^{-1} induced higher runoff, splash detachment, and sediment yield as compared to the 30 mm hr^{-1} intensity.

In general, although the general principles governing erosion loses from these small erosion pans should operate in the field, caution is however advised in extending the results of such small laboratory studies directly to predict field conditions. Therefore, it is advisable to conduct similar experiments in the field in order to correlate and calibrate the results with the data obtained in the laboratory.