CHAPTER 4

EFFECT OF SOIL TEXTURE, SLOPE GRADIENT AND RAINFALL INTENSITY ON RUNOFF AND EROSION

4.1 Introduction

Soil erosion by water occurs due to complex interactions of sub processes between detachment and transport of soil materials. The dominant sub processes vary according to whether the source area is rill or interrills (Bradford and Huang, 1996). In both cases however, although the mechanism may differ, the main reasons for soil erosion include soil characteristics, rainfall characteristics, topography, soil surface and cover situation as well as the land use and management history. Among the topographic features, slope affects soil erosion through its morphological characteristics and aspect (Torri, 1996). One of these morphological characteristics, namely slope gradient was introduced in quantitative relationships estimating soil loss (Zingg, 1940; Wischeiemer and Smith, 1978). The effect of slope on erosion has been studied extensively, with conclusions that overall erosion rates increase with increasing slope steepness (Zingg, 1940; Van Liew and Saxton, 1983; Grosh and Jarrett, 1994). Poesen (1987) also indicated that runoff and erosion usually increase with increase in slope gradient but in unstable soils that tend to seal, the effect of slope on infiltration rate and runoff can be complementary. With increase in slope angle there may be a tendency of seal erosion and subsequent increase in infiltration rate and decrease in runoff despite the fact that velocity of runoff increases with increase in slope gradient. According to Poesen (1984), as slope steepness increases, the number of drop impacts per unit surface area and the drop impacts energy both decrease thereby decreasing splash detachment. On the other hand, as slope steep-ness increases, degree of surface sealing decreases and rate of soil resistance or strength decreases thereby increasing splash detachment (Poesen, 1984). Bradford and Huang (1996), also indicated that the effect of slope length and slope steepness on particle detachment by overland flow is negligible for interrill areas although on very steep and long slopes interrill erosion may occur for very short distances (centimetres). The discussion in this chapter primarily focuses on interrill erosion processes and some of the factors that affect it.

Several authors indicated the importance of soil texture in determining aggregate stability, infiltration rate, runoff and erosion (Trott and Singer, 1983; Obi et al., 1989; Gollany, etal 1991; Le Bissonnais and Singer, 1993). According to Bradford and Huang (1992), soil texture seems to be one of the most important soil variables influencing soil surface sealing and splash detachment. Although crusts can form on soils of any texture, soils with high silt contents are more conducive to surface sealing (Tackett and Pearson, 1965). Le Bissonnais (1996) also indicated that soil erodibility increases when silt and fine sand fraction increases and clay decreases. Bradford and Huang (1992) obtained a negative correlation between silt and infiltration rate under simulated rainfall. The same result was reported earlier by Bradford et al. (1987) with different kinds of soils. Obi et al., (1989) working with various sandy soils in Nigeria found a negative correlation between sand content and runoff and erosion. Similar significant negative correlation between coarse sand and erosion rate was reported by Trott and Singer (1983).

It is well established that the amount of soil that is detached by a particular rain event is related to the intensity at which this rain falls. Smaller drops that dominate low intensity rainfall are less efficient in detaching soil (Sharma and Gupta, 1989; Salles and Poesen, 2000) but at high intensity rainfall, saturation and ponding (at least at low depths) may increase the efficiency of detachment (Torri et al., 1987). Different relationships between rainfall intensity and kinetic energy have been described. Some researchers reported a direct relationship (van Dijk et al., 2002). Logarismic (Wischmeier and Smith, 1978), and exponential (Kinnel, 1980) equations were also developed to describe the relationship between rainfall intensity and kinetic energy.

Surface sealing is one of the reasons why infiltration rates decrease with time (Mannering, 1967). This decrease is a major cause of increased surface runoff and erosion (Moldenhauer and Long, 1964). Mamedov et al. (2000) also indicated that surface sealing as well as natural low infiltration rate are the main reasons for runoff initiation. Although reports are available on the magnitude and extent of damage of soil erosion, little has been done to quantify the interactive effects of soil texture, slope and rainfall intensity on surface sealing, infiltration, runoff, and soil loss.

The aims of this experiment were therefore to

- study the effect of soil texture on seal formation and subsequent impact on infiltration, runoff and erosion,
- compare the effect of two rainfall intensities on different erosion parameters,
- determine the effect of slope gradient on seal formation, infiltration, soil erodibilty, runoff and erosion and
- and examine the interaction effects of soil texture, rainfall intensity and slope gradient on various erosion parameters.

4.2 Materials and methods

Soil texture was determined by pipette method (Day, 1965) and the textural classes of the major soils of Harerge, eastern Ethiopia, are presented on the textural triangle (Fig.4.1). To study the influence of soil texture on soil erosion parameters, three soil types whose particles sizes are dominated by any of the three soil separates sand, silt or clay were selected from these soils. The clay contents of Bedessa and AU vertisol are both high enough to represent the clay dominated soils for this experiment but AU vertisol was selected due to its relative accessibility in terms of distance from the laboratory. For silt-dominated soils, the Diredawa soil was selected. Accordingly, both Babile and AU Alluvial are comparable in terms of their high sand content but AU alluvial was selected due to its relative accessibility. Once the soils were selected, representative top (0-15cm) soil samples were collected for the rainfall simulation experiment. Some physical and chemical properties of the soils used in this study are presented in Table 2.3 of chapter 2.

An Erosion box (pan) that is 554 mm long, 206 mm wide, and 85 mm deep was perforated at the bottom to allow free drainage and pieces of cotton cloth was placed on it to prevent soil loss through the perforated bottom. Approximately 85mm thick layers of disturbed soil samples that were air dried, crushed to pass through 4 mm sieve were mixed thoroughly and packed in the box based on the bulk densities of the soils under consideration. Soils that tend to swell upon wetting were packed in such a way that some 10mm of the tray depth was left unfilled on top to reduce errors due to overflow of the soil out of the tray by swelling.

A rotating disc rainfall simulator of the type described by Morin et al. (1967) was used in this experiment to apply rainfall at intensity of 30 or 60mm hr^{-1}. Rainfall intensity was controlled by changing the aperture size of the disc, its speed and the pressure at the nozzle. After calibrating and selecting the appropriate combination of these control devices for specific rainfall intensity, the rain was applied to the air-dry soils packed in the erosion tray that were set at slope gradients of either 5, 10 or 15° each with three replications. The characteristics of the simulated rainfall are presented in chapter 2.

Overland flow and the sediment suspended in it were measured at five minutes interval as soon as runoff started. These were collected in plastic beakers that were placed under the runoff outlet of the erosion tray. The sediment yield, which is referred to as the amount of eroded sediment that leaves a specific area of land in a given time, was determined after oven-drying the runoff and weighing the sediments. These values didnnot include splashed sediments. Splash volume was collected from the beginning of the rainfall simulation at five minutes interval. Sediments caught by the splashboards surrounding the erosion plot were washed into splash collectors at every five minutes. The weight of splashed soil was determined after oven drying.

The effects of texture, slope gradients and rainfall intensity on the erosion parameters including total runoff, sediment and splash yields after the one-hour rainfall event and their trends during each rainfall event are discussed.

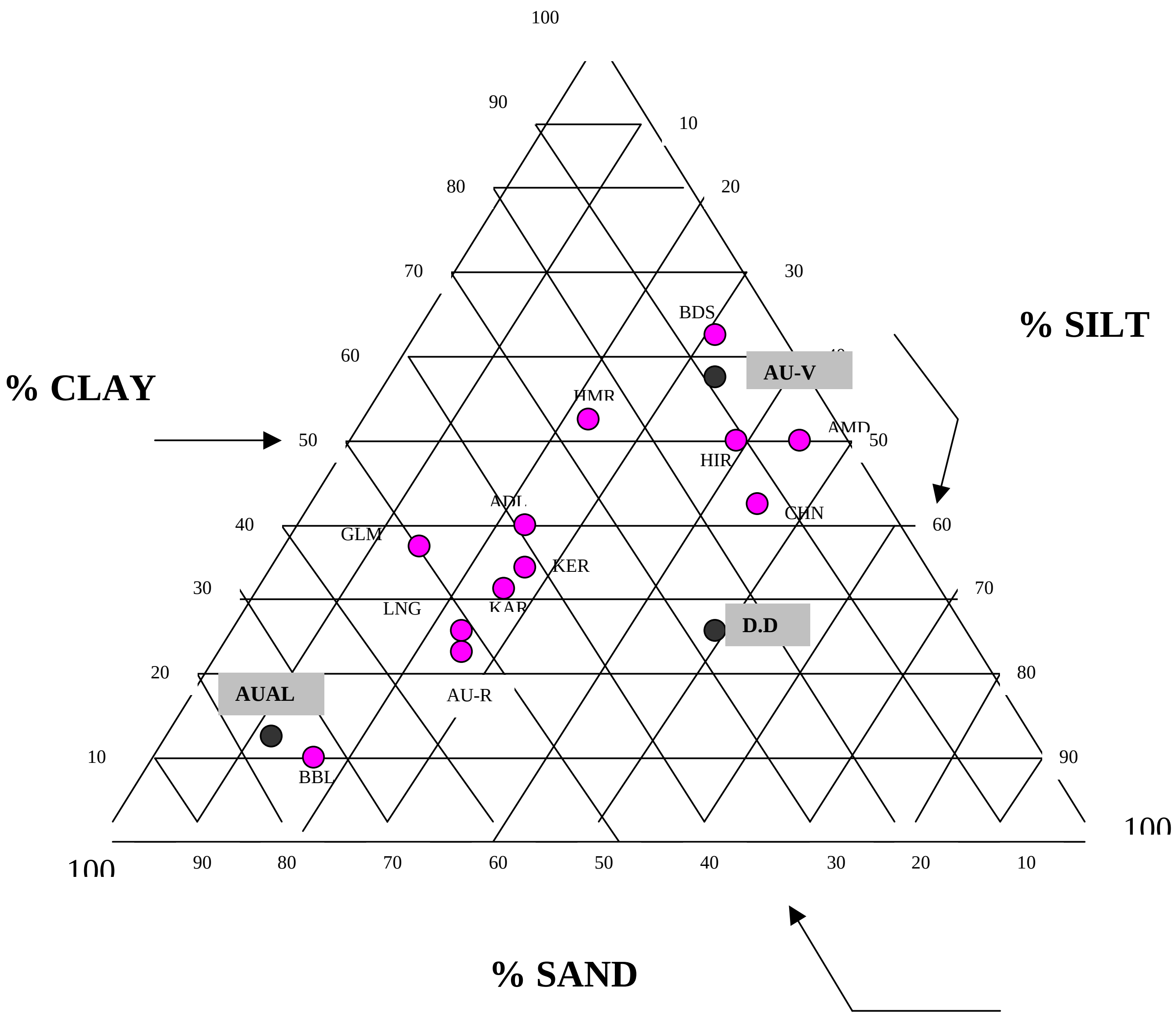


Fig. 4.1 Textures of selected soils from Harerge, eastern Ethiopia.

BD=Bedessa, HMR= Hamaressa, AU-V= Vertisols of Alemaya University campus, AMD=Amadle, HIR= Hirna, CHN= Chinaksen, ADL= Adele, KE=Kersa, GLM=Gelemso, KAR= Karamara, LNG=Lange, AU-R= regosols of Alemaya University, AU-AL=Alluvial sand of Alemaya University, BBL= Babile, DD=Diredawa

The amount of water that infiltrated into the soil was calculated as the difference between water applied to the erosion tray and that lost from the surface of the tray.

Splash volume was taken as water lost from the erosion tray because in this experiment, no replacement of the splashed material was allowed. Hence, overland flow and splash volume were regarded as the only water losses from the surface of the erosion tray. The following procedures and assumptions were applied to calculate the infiltration rate:

- For every simulation run, the first reading of splash volume was subtracted from other consecutive readings to adjust for the amount of water that falls directly on the splashboards and troughs and collected by splash collectors when rainfall is applied on an empty (without soil) plot.

- The amount of rainfall is calculated by dividing the amount of water collected by the plot to the area of the plot.

- It is also assumed that no water ponding occurs on the soil surface. The amount of water infiltrated is considered to be equal to the amount of water received on the erosion plot (see equation 4.1) minus runoff and net splash volume. Net splash volume is the difference between a splash volume collected at each 5 minutes interval and that collected during the first 5 minutes of the rainfall event. This procedure may overestimate infiltration rate to some extent especially during the beginning of the rainfall event.

$$Q = IAt/600 \quad \text{..(4.1)}$$

Where, Q= Volume (ml) of water applied to the plots of area A per hour,

I= Intensity in mm hr^{-1},

A= Cross-sectional area of the erosion plot (cm^2) and

t= time elapsed since the onset of rainfall (min.)

The influence of seal formation was observed by the change in the infiltration characteristics of the soils.

Special considerations

The tray used in this study doesn't allow replacement of the water and sediments that are splashed out of the plot area. Taking this into consideration, and assuming that the water and portion of the sediments that were splashed out of the plot would have contributed to the total runoff and sediment yield respectively, an attempt was made to include these values to the runoff and sediment contained in it. Therefore, runoff in this study is considered as the sum of overland flow and splashed water. In this procedure, the fraction of sand and water stable aggregates in the splashed sediment were deducted from the total splash weight assuming that these are too heavy to be transported by the thin overland flow that occurs on such small erosion plots of short slope length. The equation is:

$$S.Y = W+\{S\,[1-(PWSA+Psa)/100]\} \qquad (4.2)$$

Where,

S.Y = Total sediment yield (kg m^{-2})
W = Weight of wash off soil (sediment in runoff) (kg m^{-2})
S = total weight of sediment in splash (kg m^{-2})
PWSA = percent water stable aggregates
Psa = percent sand

However, the total sediment yield obtained using this equation didn't comply with the actual field observations and soil properties. On the other hand, when the sediment in runoff and splash weight were handled separately, the correlations with most of the soil properties were more relevant to the actual expectations.

Therefore, as it was difficult to accurately estimate the proportion of sediments in splash that would have contributed to sediment yield, both wash off soil and splash weight were discussed separately and sediment yield in this text refers to only the amount of sediment in overland flow. The sediments in the splash were used as indicators of the susceptibility of the soils to detachment by raindrop impact. It is however, important to note that equation 4.2 may provide a reasonable information if the proportion of fine and coarse sands in the total sand fraction are known.

Statistical analysis

The experimental layout was a completely randomized block less design (CRD). Treatments consist of three different textured soils (clay, silt, or sand dominated), three slope gradients (5, 10 and 15 degrees) and two rainfall intensities (30 and 60mm/hr). Statistical analyses were done using a SAS computer software (TCP 3270 version 2.5). Correlation analysis was also done between the dependent and independent variables. The level of probability used in this text was p = 0.05 unless specified.

4.3 Results and discussion

4.3.1 Analysis of total erosion parameters as affected by soil texture, slope gradient and rainfall intensity

4.3.1.1 Runoff

Analysis of variance of the effects of soil texture, slope gradient and rainfall intensity on the total runoff collected during the one-hour simulated rainfall revealed a highly significant ($P<0.0001$) interaction.

On the sandy alluvial soils from the Alemaya university campus, little runoff was collected that was also not significantly different between the three slope gradients at both 30 and 60mmhr^{-1} rainfall intensity (Fig. 4.2). Runoff occurs when rainfall intensity exceeds infiltration rate. As expected, the high infiltration capacity of sandy soils resulted in a relatively low runoff as compared to the other similarly treated soils.

According to Nearing et al. (1991), slope has the most direct effect on the erosivity of overland flow by determining its stream power and runoff increases with increase in slope gradient. However, soil surface conditions and storm characteristics also modify its effect on runoff and soil loss. The consequence of this is the absence of a unique relationship between runoff and slope characteristics unless long-term trends are of interest (Torri, 1996). The results in this experiment indicate that the little runoff collected from sandy soils was not significantly affected by the applied slope gradients. The limited effect of slope gradient on runoff (total volume) could also be due to the fact that 'infiltration' is a 'soil physical property' said to be independent of slope gradient. However, the runoff velocity is slope dependent.

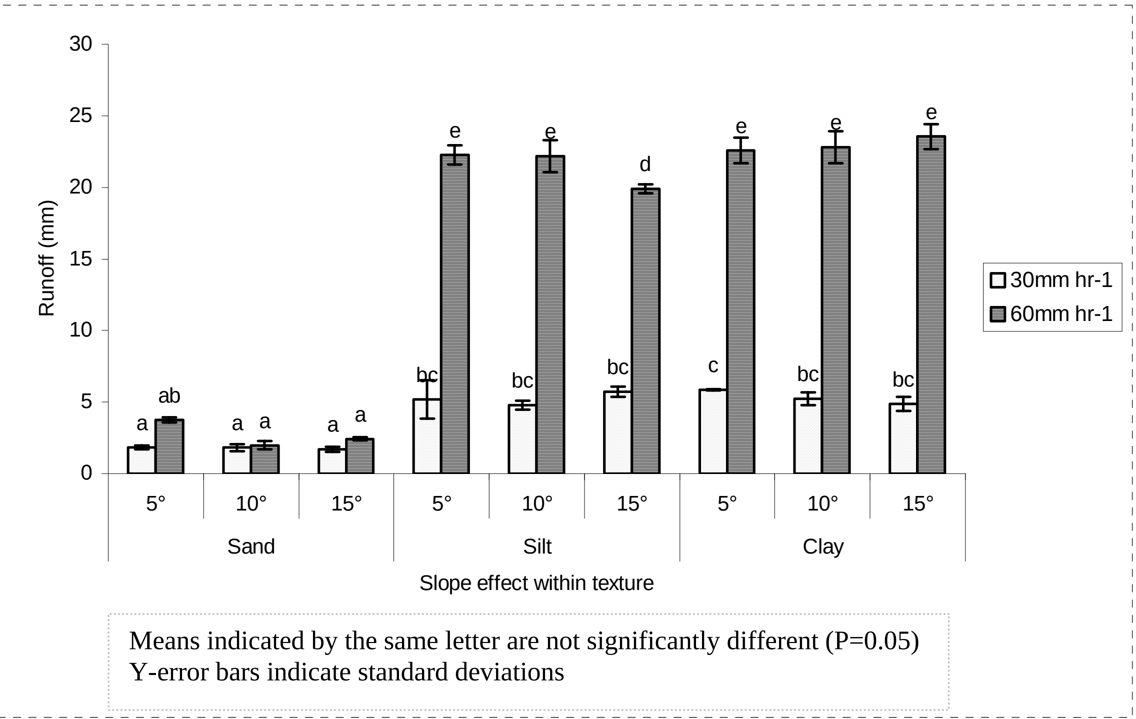


Fig. 4.2 Mean runoff (mm) at different slope gradients and rainfall intensities for the three soil textural classes.

On the Diredawa silty soils, a higher (P<0.001) runoff volume was collected at 60mm/hr rainfall intensity as compared to that for 30 mm hr^{-1} under all slope gradients (Fig. 4.2). At 30 mm hr^{-1} intensity, no significant differences in runoff among the slope gradients were observed. However, at a rainfall intensity of 60mm/hr, the runoff at 5 and 10° slope gradients were significantly higher than that of 15° slope (P=0.02 and P<0.03 respectively). The relatively low runoff observed at 15^0 slope could be ascribed to a decrease in the degree of surface sealing with increase in slope steepness (Poesen, 1984; Bradford and Huang, 1996) and a subsequent increase in infiltration.

On the clay-dominated swelling soils collected from Alemaya university vertisol, runoff was not significantly different along the slope gradients at both 30 and 60 mm/hr intensity (Fig 4.2).

The effect of soil texture and rainfall intensity on runoff seems to be more pronounced than that of slope gradient. The limited effect of slope gradient on runoff in this laboratory rainfall simulation study could be among others related to the very short slope length of the erosion plots unlike the actual field conditions because the slope length is too short for the sheet flow to develop into channels (rills) and form high flow depth. Hairsine and Rose (1991) proposed that when the flow depth is less than or equal to a breakthrough depth and flow driven processes are inactive, erosion is independent of slope.

In general, runoff followed a decreasing order of magnitude as follows: Clay-60mm/hr, Silt-60 mm hr^{-1}, Clay-30 mm hr^{-1}, Silt 30 mm hr^{-1}, Sand 60 mm $hr^{-1}$and sand-30 mm hr^{-1} regardless of the slope gradient.

At least a 250% increase in runoff volume has been observed when rainfall intensity is increased from 30 mm hr^{-1} to 60 mm hr^{-1} for the silt and clay dominated soils. This clearly indicates that the effect of rainfall intensity on runoff is more prominent than the other two variables considered in this study.

4.3.1.2 Sediment yield

A significant interaction among soil texture, slope gradient and rainfall intensity on sediment yield was observed. Therefore, the effect of any one factor on sediment yield cannot be discussed with out taking the other two factors into consideration.

At rainfall intensity of 30 mm hr^{-1}, no sediment yield was recorded on sandy soil under all slope gradients (Fig. 4.3) because of the high infiltration rate and no runoff that would have otherwise carried the sediments down the slope. However, at 60 mm hr^{-1} intensity, some sediment yield has been recorded at low slope gradients though none are statistically significant. Although the sand particles are relatively loosely aggregated, they are too heavy to be transported down the slope unless sufficient velocity of water is applied which is however not attained due to high infiltration rate. Surface sealing and low infiltration rate are the main reasons for runoff initiation and for sediment transport (Mamedov et al., 2000). The data on sediment yield among the slope gradients followed a similar trend with that of runoff on sandy soils. Hence, low runoff and sediment yield could also be an indication of no seal formation on the sandy soils.

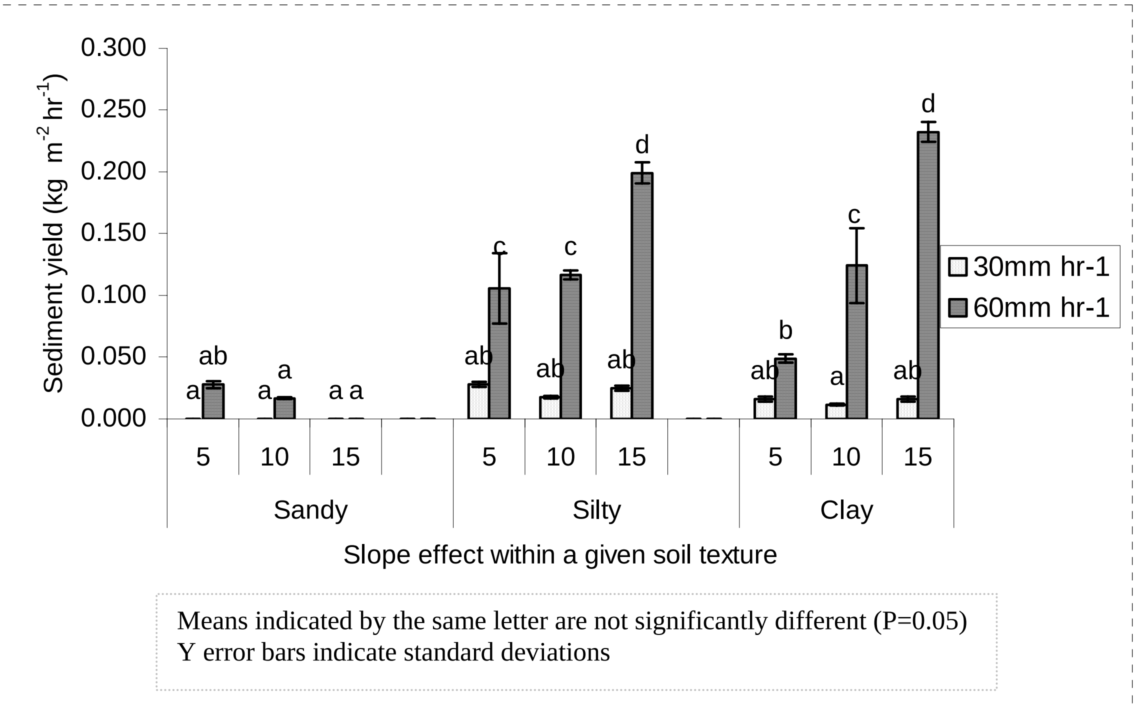


Fig.4.3 Change in sediment yield as influenced by rainfall intensity, slope gradient and texture

Silt dominated soils were found to be more susceptible to particle detachment as sediment yield at both rainfall intensities compared to sandy soils. This could be due to the relative transportability of fine and none aggregated silt particles (Le Bissonnais, 1996) as compared to the larger sand particles. Moreover, silt dominated soils also have lower infiltration rates than sandy soils which will enhance runoff and sediment yield. This high erodibility of the silt-dominated soils is line with many other studies (Romkens et al., 1977; Bradford et al., 1987; Bradford and Huang, 1992) that reported a negative correlation between silt content and infiltration rate. Ben-Hur et al. (1985) also indicated that medium textured soils (silty and loamy sand) are often the most susceptible to crusting and erosion. It has also been stressed however that interaction between texture and other parameters like clay mineralogy and organic matter content could modify this relationship.

The effect of slope gradients is not significant at the 30 mm hr^{-1} intensity for the silt soils. Sediment yield was significantly higher at 60 mm hr^{-1} than for 30 mm hr^{-1} for all slopes. This is mainly due to the fact that infiltration rate is greatly exceeded at this high intensity rainfall. At the 60 mm hr^{-1}intensity, a significantly higher sediment yield was recorded on 15° ($P<0.0001$) slope while the difference was not significant on slopes of 5° and 10°. The absence of significant difference between sediment yield recorded on 5 and 10° slope gradients on silt dominated soils as compared to an increasing trend observed in clay soils (Fig. 4.3) can be attributed to the more susceptibility of the loosely aggregated silt dominated soils to detachment and transport by low velocity overland flow induced by lower slope gradients as compared to the well aggregated clay soils that could be too heavy to be transported by such low velocity flows.

The sediment yield on clay soils followed almost similar trends (Fig 4.3). At 30 mm hr^{-1}, it was not significantly different among the slope gradients. Application of rainfall at 60 mm hr^{-1} resulted in a higher ($P<0.0001$) sediment yield with increasing slope gradient. These results are in agreement with the work of Warrington et al. (1989) who reported a rapid increase in soil loss with increasing slope gradient which ranged between 5 and 25% on smectitic soils. Working with rainfall simulation in South Africa, Stern (1990) also reported higher particle concentration in runoff on the 30% slope gradient as compared to the 5% on Msinga kaolinitic clay loams and Jozini illitic sandy loam soils.

In general, rainfall at an intensity of 30 mm hr^{-1} did not produce a significant difference in sediment yield for all the textural classes used at 5° slope (Fig 4.3). But at 60 mm hr^{-1} intensity on the same slope, significantly higher sediment yield was recorded on silty and clay dominated soils. The sediment yield for clay soils at the 60 mm hr^{-1} intensity did not differ significantly from that for silt soils at similar intensity especially at 10° (P = 0.656) and 15°(P=0.0566) slopes. While indicating the importance of aggregate breakdown in the process of crusting, Le Bissonnais (1996) indicated the equal importance of the characteristics of the detached particles such as their sizes and aggregate stability.

4.3.1.3 Splash erosion

Splash erosion occurs due to raindrop impact that initiates soil detachment. The impact droplets are transferred outward from the center of the impact while encapsulating solids and carrying them to the landing point (Sharma, 1996). Unlike the field conditions where the net splash transport is minimum, the design of the erosion tray in this laboratory experiment doesn't allow replacement of the splashed materials that are transported out of the plot area. The amounts of sediments detached and transported by the raindrop impact are considered as indices that indicate the relative degree of susceptibility of the soils to detachment under various treatments. Hence, the splash values in this experiment should not be extrapolated to larger areas but can be used to compare treatment effects.

As presented in Fig 4.4, soil texture, slope gradient and rainfall intensity showed a highly significant interaction effect on splash erosion ($P<0.001$). For all the different textured soils and slope gradients, at the high intensity rainfall (60 mm hr^{-1}), treatments produced more sediments due to splash compared to the low (30 mm hr^{-1}) intensity. It has been reported (Agassi et al., 1994) that, the amount of soil splash increases as both rainfall intensity and rainfall energy increases though the rate of increase will depend on factors such as antecedent soil water content, mechanism of aggregate breakdown, and soil properties such as clay mineralogy, texture, organic matter and exchangeable sodium content.

Among the different slopes on sandy soils, only small differences occurred that was seldom significant. At 30 mm hr^{-1} rainfall, significant difference (P=0.0221) was observed only between 10 and 15^{o} slope the latter being higher. At 60 mm hr^{-1} rainfall, all slopes showed significant differences, but the relationship was not linear with increasing slope gradients. Poesen (1985) and Morgan (1978) also found no significant relationships between detachment and slope. On the other hand, several studies (such as Quansah, 1981; Mosley 1973, Grosh and Jarrett, 1994) reported greater splash detachment with increase in slope gradient.

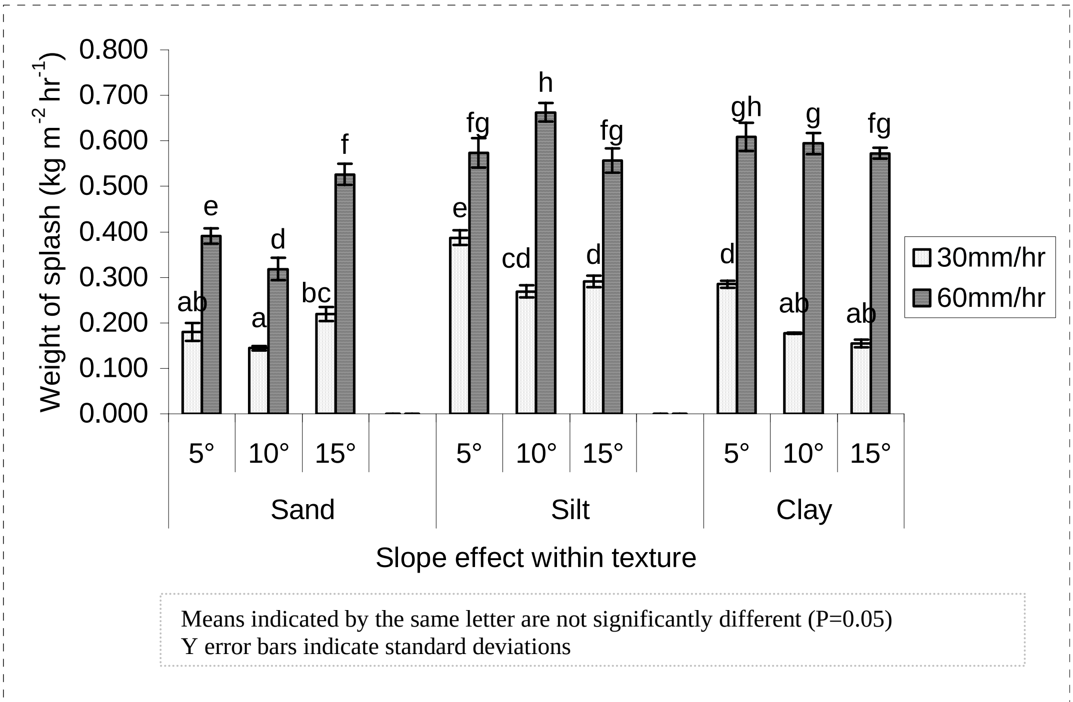


Fig. 4.4 Mean splash weight (kg m^{-2} hr^{-1}) as affected by slope gradient and rainfall intensity within soil textural classes.

In the case of silty soils, the relatively low splash erosion on 5° slope as compared to the one on 10° slope gradient at 60 mm hr^{-1} intensity could be explained by two possible reasons. For one thing, the degree of surface sealing is high at low slope gradient resulting in relative increase in the resistance of the soil particles against the impact of raindrop. Seal development increases the shear strength of the soil surface (Bradford et al., 1987; Mamedov et al., 2000) and thus reduces soil detachment (Moore and Singer, 1990). The other possible reason could be attributed to possibility of high surface water depth at low slope gradients mainly due to slow velocity of overland flow, which might have resulted in a subsequent decrease in splash as compared to the one the high slope gradient. Moses and Green (1983) also indicated that airborne detachment appears to be most intense at zero water depth and is greatly reduced at higher water depths depending on drop size. The relatively low splash erosion from silt soils on 15° slope as compared to the one on 10° slope seems to be contrary to the general expectation of the relationship between slope gradient and splash erosion. Nevertheless, this low splash erosion on steep slopes could also be due to the relative decrease in the amount of drops impacting the soil surface with increase in slope gradient. But this relationship was not consistent among the different soil types and needs further investigation.

On the soils with high clay content, slight decrease in splash weight was observed with increasing slope gradient at both 30 and 60 mm hr^{-1} intensity although the difference is not significant for the latter. The relatively higher splash erosion on 5° slope gradient as compared to the higher slope gradients could be due to the difference in the number of drop impacts received on the soil surface at various slope gradients. In a rainfall simulation study at intensity of 65 mm hr^{-1}, Bradford and Huang (1996) found that for clay loam and clay soils, splash values on 20 % slope were less than on 9%. They also reported a significant interaction between soil properties (aggregate stability, soil strength, and surface sealing) and slope steepness.

In general, for all slope gradients and rainfall intensities, higher splash was observed on silty soils though it was seldom significantly different from clay soils at 60mm hr^{-1} intensity. Splash was significantly lower on sandy soils.

4.3.2 Trends of erosion parameters during rainfall event

For the trend analysis with time, runoff, infiltration rate, sediment yield and splash erosion data that were determined at every five minutes since their initiation was used. Since the overall trend for most of the erosion parameters was similar at 30 mm hr^{-1} and 60 mm hr^{-1} of rainfall intensity, only those for 60 mm hr^{-1} will be discussed in this text.

4.3.2.1 Infiltration rate

The infiltration rate of the three soils followed a clearly different pattern (Fig. 4.5). In sandy soils, steady state infiltration rate was attained during the early minutes of the rainfall event with a higher infiltration rate maintained throughout the rainfall event under all slope gradients. The higher infiltration rate observed in this sandy soils could be an indication of no seal formation and presence of large number or macropores. Variations in slope gradient did not result in a significant difference in infiltration rate for the sandy soils.

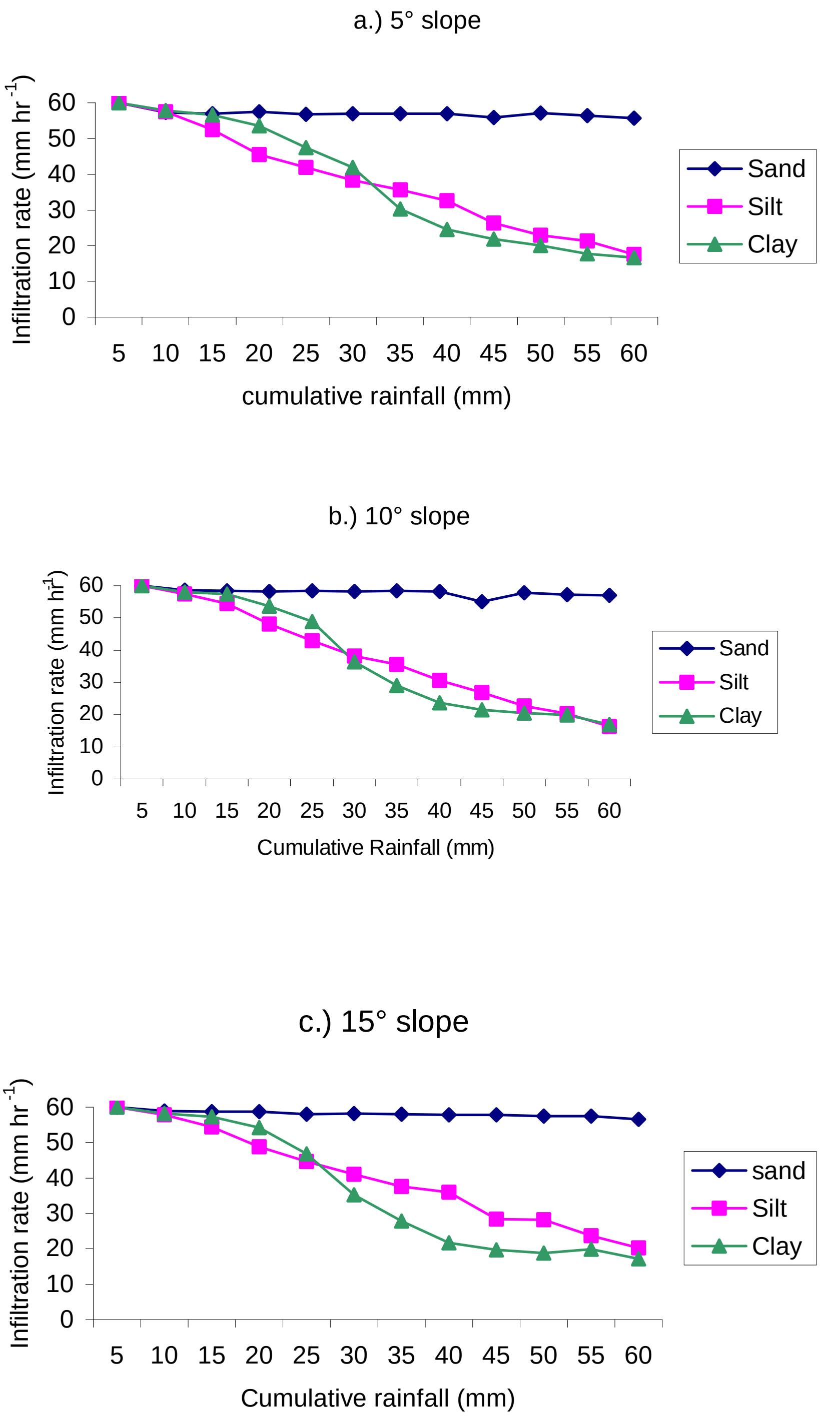


Fig. 4.5 Infiltration (mm hr^{-1}) curves of three soil textures under three slope gradients at 60 mm hr^{-1} rainfall intensity

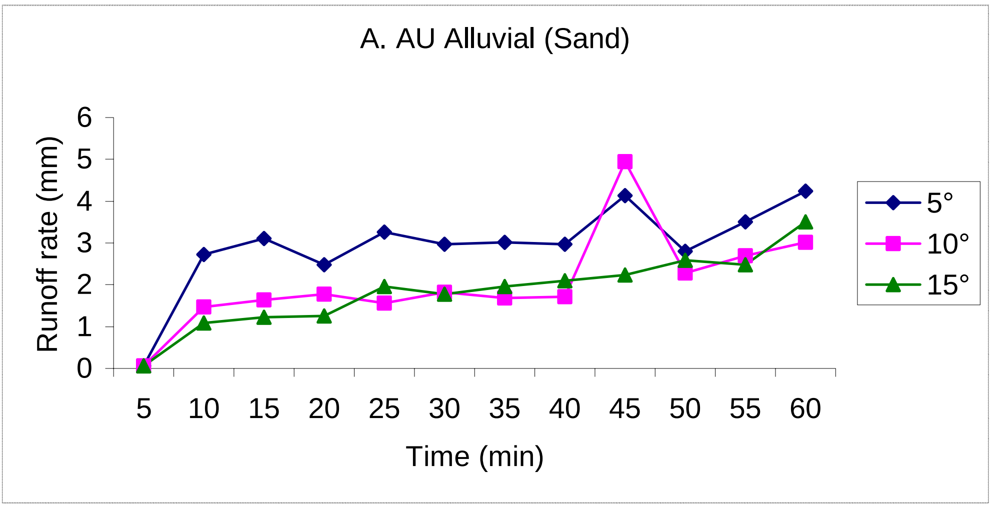
In the case of silty soils, steady state infiltration was not attained during the whole rainfall event. A continuous decrease in infiltration rate was observed over the 60 minutes time. This reduction in infiltration rate could be attributed to continuous breakdown of soil aggregates that gradually clog pore spaces and increase the rate of seal formation.

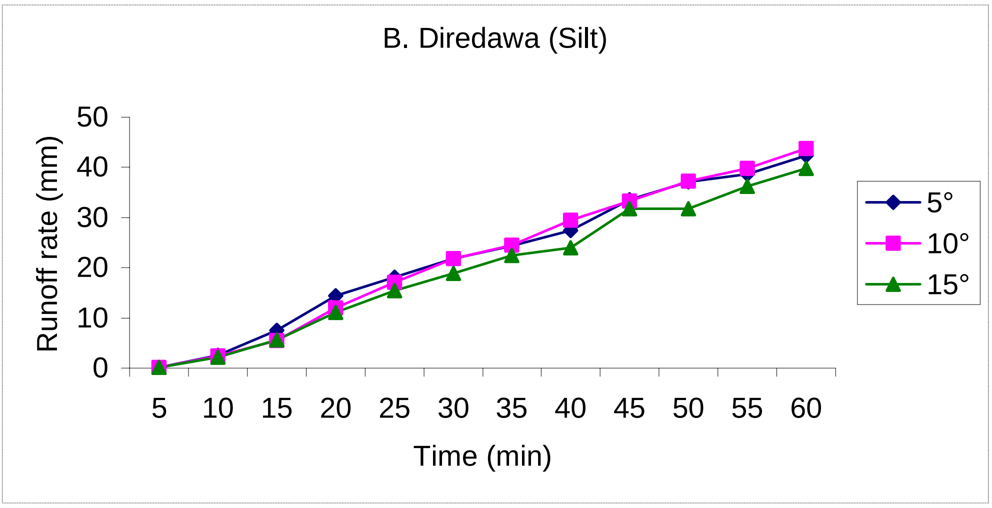
For the first half hours of the rainfall event in clay-dominated soils, the infiltration rate was greater than those of silt dominated soils. This could be due to the high soil aggregation and aggregate stability in clay-dominated soils. However, the infiltration rates decreased to lower values than that of the silt soils then after. This could be ascribed to the swelling properties of the clay soils. Few minutes before the end of the one-hour rainfall simulation period, the infiltration rate in clay soil reached its steady state indicating the final stage of swelling. At this steady state infiltration rate, runoff seems to have approached its peak (Fig.4.6).

4.3.2.2 Runoff

Little runoff was observed on alluvial sands if at all (Fig.4.6A). It rarely exceeded 4mm at each five-minute interval of rainfall. This is mainly due to the coarse textured soil that encourages more infiltration and drainage than runoff. Even the little amount recorded is due to the added splash water to the total runoff. The other possible reason could be due to the entry of fore ward splashes into the runoff outlet rather than overland flow. The fact that relatively higher runoff was recorded at 5° slope as compared to the higher slope gradients could also be due to similar anomaly.

For Diredawa silt soils (Fig. 4.6B), runoff increased linearly from the time it commenced till the end of the simulation period under all slope gradients. This could be due to the gradual surface sealing and subsequent reduction in infiltration that will end up in increased runoff with time until all the pores get clogged and runoff becomes constant. The fact that higher runoff rates have been observed on 5° and 10° slopes than that on the 15° slope seems to contradict the general common understanding that runoff increases with slope gradient. It can however, be attributed





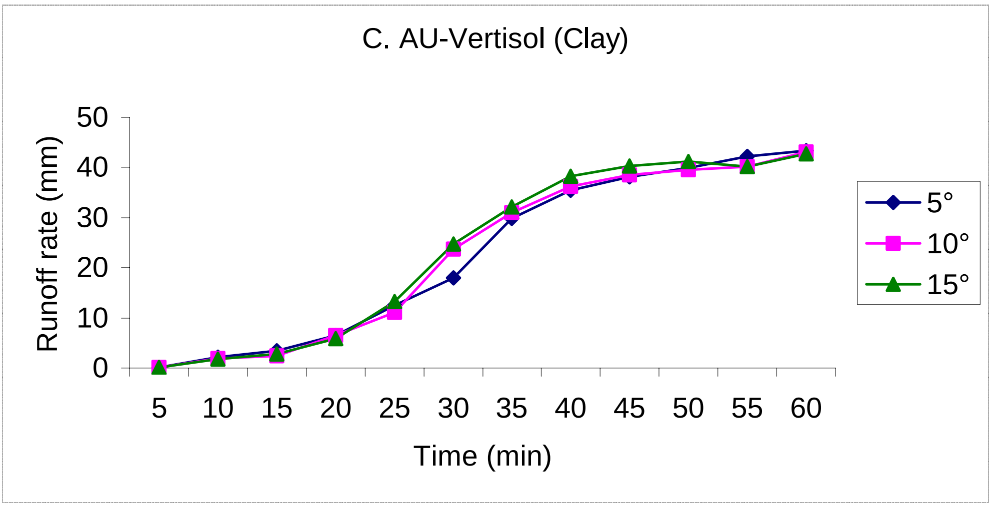


Fig. 4.6 Runoff (mm) trends at various slope gradients for the sand, silt and clay dominated soils

to decrease in the rate of surface sealing at high slope gradients thereby increasing the infiltration rate and leading to low runoff.

On the clay-dominated soils, runoff increased slowly for the first 15 minutes with sharp increase between 25 and 30 minutes since its commencement and then increased slowly again that almost became constant after about 50 minutes of the rainfall period (Fig 4.6C). The rate of runoff during the rainfall event on this clay-dominated soil was high at high slope gradients. Runoff is usually initiated due to surface sealing and/or natural low infiltration rate of soils. The clay-dominated soils have naturally low infiltration rates due to the abundance of fine particles and subsequent micro-pores as well as their tendency to swell. At low slope gradients, the water gets sufficient time to soak into the soil resulting in higher infiltration rate and reduced runoff.

4.3.2.3 Sediment yield

For sand dominated soils, sediment yield followed a similar trend to that of runoff and will therefore receive a similar explanation. The general trends of both runoff and sediment yield on sandy soils were irregular among the slope gradients. Besides, the amounts of runoff and sediment yield at any one point during the simulation was very small.

For the silt-dominated soils of Diredawa, sediment yield was almost constant from the time of runoff commencement up to about 50 minutes and showed a rapid increase thereafter (Fig. 4. 7B). The rate of increase is higher at higher slope gradients. This increase in the rate of sediment yield at the latter stage of rainfall could be attributed to the increase in runoff concentration as thicker layer of water flows at faster speeds that may even wash the seals formed during the early stages of rainfall.

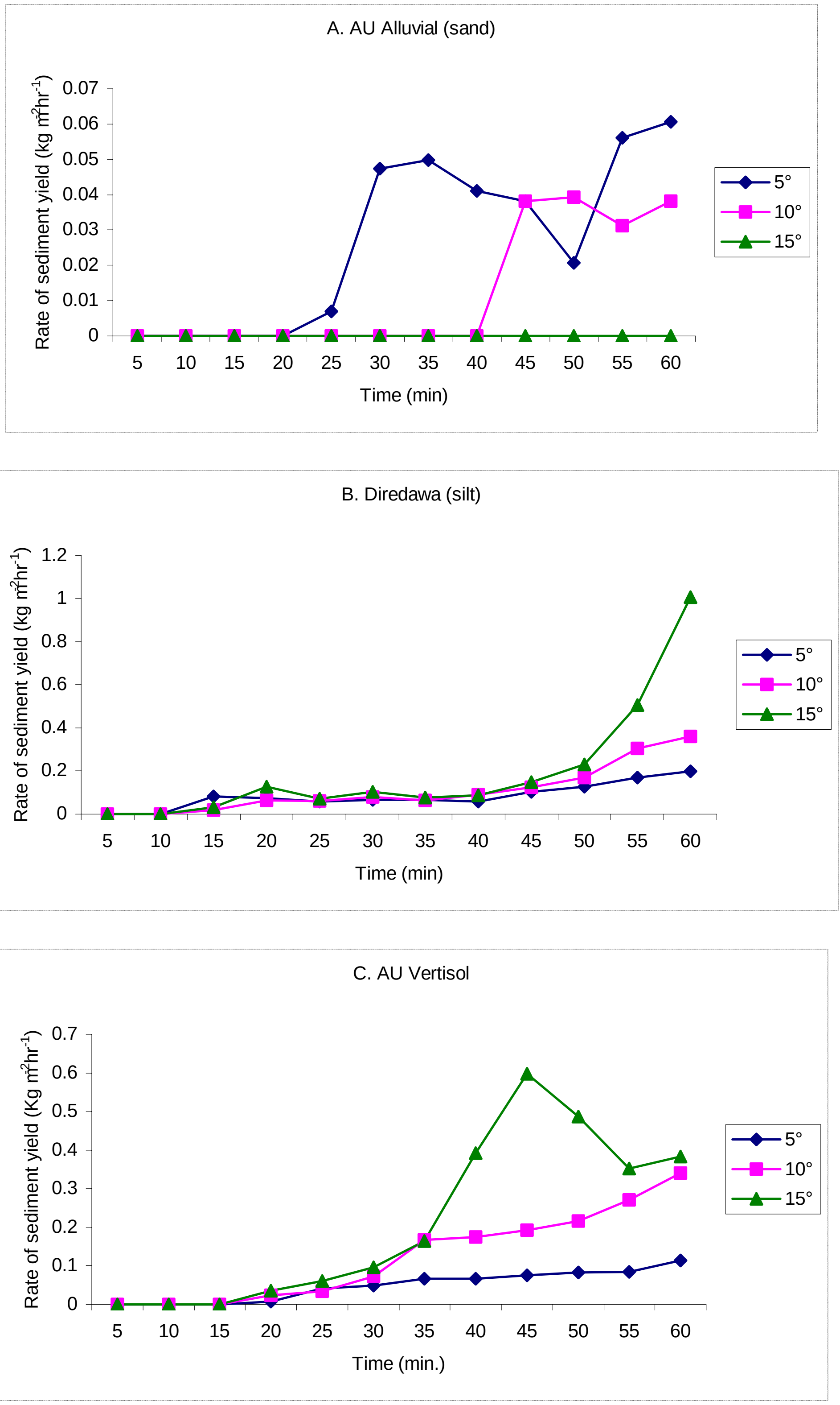


Fig. 4.7 Trends of sediment yield (kg m^{-2} hr^{-1}) at various slope gradients for the sand, silt and clay dominated soils at rainfall intensity of 60mm hr^{-1}.

For clay dominated soils of Alemaya university vertisols, sediment yield increased with increase in time of rainfall application for all slope gradients from about 15 minutes onwards. The rate of increase was high at the higher slope gradients. The trend of sediment yield at the slope gradient of 15° on the clay soils is in agreement with the one presented by Stern (1990) for his control plots on Msinga clay loams at 30% slope gradient. The rapid increase in sediment concentration is associated with increase in runoff (Fig. 4.7C) and availability of loose particles on the soil surface. With depletion of the loose particles and development of compacted seals (after 50 minutes), the concentration of sediment in runoff subsequently decreased.

4.3.2.4 Splash detachment rate

The soil material which has been splashed from the erosion plot and captured by the splashboards that are fixed to the periphery of the plot has been washed to splash collectors at 5 minutes interval and was recorded as splash weight after oven drying. The values reported here are averages of three replicates.

For alluvial sand, splash weight increased almost linearly with increase in time for all slope gradients under consideration (Fig. 4.8A). It was slightly larger in magnitude at 15° slope as compared to the 5° and 10° slopes throughout the one-hour simulation time. The splash weight recorded at 10° slope was however lower than the one at 5° slope all the way during the simulation period. Though the difference may not be significant, such result is usually unexpected because more downward splash is normally expected at higher than lower slope gradients. But it could still be related to the variation in the total number of drop impacts per unit area of the plots at various slope gradients. During the early dry run, splash from sandy soils was very small and increased with increasing wetness of the soil. This could be attributed to the absorption of most of the incoming water by the dry and relatively rough soil surface and subsequent reduction in the splash energy. But as the soil gets wetter and the surface becomes smooth, splash energy increases and more water bounces from the soil surface carrying loose sediments.

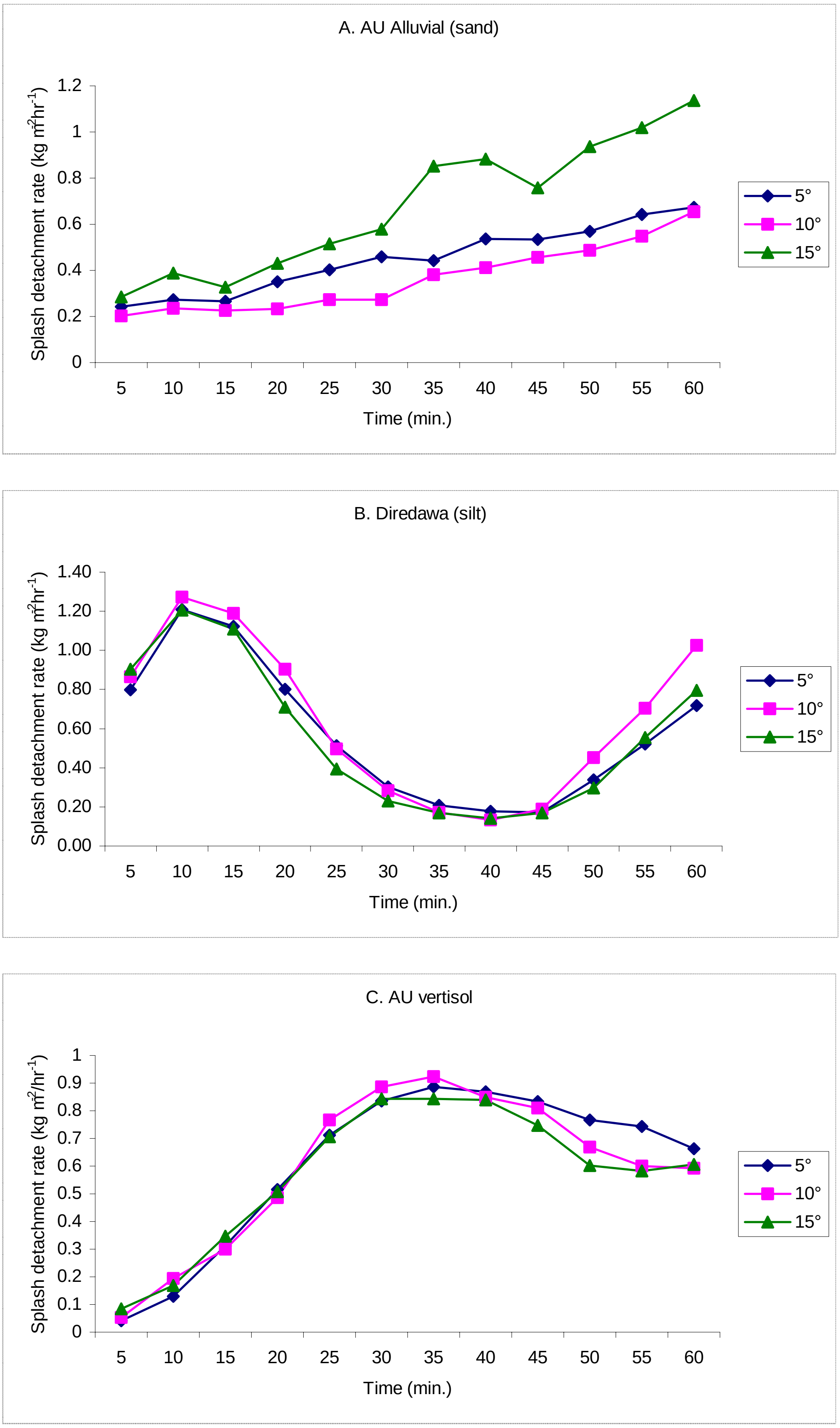


Fig. 4.8 Trends of splash detachment rates (kg m^{-2} hr^{-1}) at various slope gradients for the sand, silt and clay dominated soils.

For Diredawa silt soils, splash weight followed nearly a parabolic trend with time for all slope gradients. Splash weight was generally higher at 10° slope than the other two slope gradients. However, the difference doesn't seem significant. For all slope gradients, high splash weight was recorded for the first 15 minutes of rainfall and late after 45 minutes. The higher splash during the initial dry run could be due to the abundance of loose light weighted silt materials on the surface that can easily be carried by the bouncing water. However, as the soil gets wetter with time, aggregates breakdown and surface sealing occurs due to close up of soil pores by the fine particles from the broken aggregates. The coherence of these particles from the broken aggregates strongly resists the shearing force of the splashing raindrops resulting in less splash erosion. With further wetting of the soil (cumulative rainfall >50mm), the seal will disintegrate and more particles may become suspended thereby being carried by the splashing water. This indicates that silt dominated soils are prone to detachment by the impact of raindrops at the beginning of rainfall on dry surfaces and after heavy rainfall that lasts for long time (Fig.4.8B).

Splash erosion on vertisols (clay dominated soils) increased rapidly for the first 30 minutes and started declining thereafter (Fig. 4.8C). The trend of splash weight was similar for all slope gradients with no significant difference among them. The linear increase in splash weight at the early stages of rainfall could be attributed to the availability of unaggregated fine materials and partial breakdown of relatively unstable aggregates as the soil gets wetter. With further increase in cumulative rainfall (>35mm), the more stable aggregates are left behind on the surface that will disintegrate slower and produce less splash material. This has eventually lead to less splash production. Besides, when the soil is saturated and runoff starts, it results in a temporary water ponding that may increase the gap between the soil surface and the falling raindrops. Hence the splashing water bounces with little contact with the soil surface.

Comparison of the trend of the mean splash weight for the three soil textural classes reveals that silt dominated soils are more prone to splash erosion than sand and clay dominated soils at a cumulative rainfall of less than 20mm. Splash erosion increased linearly with increase in cumulative rainfall on sandy soil. A similar increase was observed for clay soils during the early stage of the run but started declining after 35minutes.

4.3.3 Correlation between some erosion parameters

Correlation analysis was performed to observe the general relationship among the various erosion parameters measured in this study. Only the total values (collected during the one hour rainfall simulation) of each erosion parameter were used for this analysis. The correlation coefficients are presented in Table 4.1.

Table 4.1 Correlation among some of the erosion parameters

	Runoff	Splash wt	Sediment yield	Water retention	Time to Runoff	Final IR
Runoff	1.00					
Splash erosion	0.80	1.00				
Sediment yield	0.83	0.70	1.00			
Water retention	0.53	0.17	0.33	1.00		
Time to Runoff	-0.74	-0.61	-0.63	-0.57	1.00	
Final Infiltration Rate	-0.51	-0.07	-0.34	-0.68	0.44	1.00

Sediment yield and splash erosion were highly and positively correlated with runoff (r= 0.83; r=0.80 respectively). Similar positive correlations were also observed on the different soils as described in chapter 3. Other studies also reported similar linear relationships between runoff and soil loss (Feleke, 1987; Singer and le Bissonnais, 1998; Sonneveled et al., 1999). This indicates that high soil erosion was associated with high runoff volume. Factors that encourage high runoff such as high rainfall intensity and medium and fine textured soils also exacerbate splash erosion. The negative correlation between the time to runoff initiation and sediment yield (r=-0.63) as well as splash weight (r=-0.61) indicate that high sediment yield and splash are collected under conditions that induce early runoff initiation. Positive correlation was also observed between sediment yield and splash erosion (r=0.70). Hence, most of the factors that affect sediment yield also tend to have a similar effect on splash erosion. Runoff and sediment yield are negatively correlated with the final infiltration rate (r=-0.51; r=-0.34 respectively) indicating that soils with high final infiltration rate are less susceptible to runoff and erosion. At this junction, it is important to note that though the amount of data used for this correlation analysis was not large enough to produce more tangible information, it would give a better view of the influence of the different factors on erosion.

4.4 Conclusion

The effect of soil texture, slope gradient and rainfall intensity on erosion parameters including runoff, sediment yield, splash erosion, and infiltration was studied under laboratory rainfall simulation. For most of the erosion parameters, the interaction effect among soil texture, slope gradient and rainfall intensity was significant. In general however, high rainfall intensity induced high runoff, sediment yield, splash and drainage. The effect of slope gradients on most of the erosion parameters was not significant as the plot size is too small to bring about a concentrated and speedy flow. The effect of soils dominated by any one of the three soil separates on the erosion parameters was largely dependent on rainfall intensity and slope gradient.

A positive correlation was found among runoff, sediment yield, and splash erosion indicating that most of the factors whose effects are studied in this experiment affect these erosion parameters similarly. For instance, final infiltration rate which is considered as an indicator of the degree of surface sealing was negatively correlated to runoff and sediment yield. This indicates the direct impact of sealing on runoff and erosion. Such information can provide a hint to the management of similar soils provided that other factors that are not considered in this study are constant. However, data obtained under laboratory rainfall simulation can't be directly applied to field conditions, as the soil characteristics, topography, soil surface phenomena as well as climatic conditions can't be represented exactly the way they are in the field. Laboratory studies are much simplification of the actual field situations. However, if interpreted with care, valuable information can be obtained from the laboratory rainfall simulation studies within a reasonably short time. This information can be used as a valuable input for further field scale studies and to make preliminary management decisions in the absence of a more comprehensive and representative data.

In this particular study, because of the nature of the experiment, which was entirely based on investigation of the interaction effects of slope gradient, soil texture and rainfall intensity on erosion parameters in the lab using simulated rainfall, no attempt was made to relate any of the results to the results of SLEMSA and USLE predictions.