CHAPTER 2

ERODIBILITY ASSESSMENT OF SOME SOILS OF HARERGE, EASTERN ETHIOPIA, BY USING RAINFALL SIMULATION

2.1 Introduction

The eastern part of Ethiopia including the Harerge region is characterized by a diverse climatic, topographic and soil conditions. This region is one of the most susceptible areas for various land degradation processes. Accelerated erosion, water stress, soil salinity and sodicity as well as soil fertility decline are among the main causes of soil degradation. The problem of soil surface crusting is also well recognized by the farmers in the Harerge region. Farmers usually cultivate the land once or twice to break the seals and increase infiltration (Fekadu, 2001). Surface sealing and crusting occur in most cultivated soils in many parts of the world and has major implications for agricultural production because of its effects on soil hydrological properties, erosion and crop establishment (Bajracharia and Lal, 1999). Soil surface seals and crusts reduce soil infiltration rate, increase soil strength and may increase erosion by increasing runoff (Le Bissonnais and Singer, 1993). Aarstad and Miller (1981) also indicated that rapid drop in infiltration rates of soils that are commonly observed during rainstorms are mainly due to surface sealing and crusting on the soil surface. According to Mamedov et al. (2000), surface sealing as well as naturally low infiltration rates of the soils are the main reasons for runoff initiation.

Different soil and climatic factors are responsible for soil sealing and crusting. These include soil texture, (Ben-Hur et al. 1985), clay mineralogy (Wakindiki and Ben-Hur, 2002), exchangeable sodium percentage (Levy and Van der Watt, 1988), organic matter content (Le Bissonnais and Arrouas, 1997; Singer and Le Bissonnais, 1998), citrate-bicarbonate-dithionite extractable Al and Fe content (Le Bissonnais and Singer, 1993; Singer and Le Bissonnais, 1998) and rainfall intensity. Although soil surface sealing and crusting is well recognized as one of the causes of soil degradation in the world, its extent and impact on agricultural production as well as its contribution to environmental degradation has neither been assessed nor well documented in Ethiopia in general and in the Harerge region in particular.

The objectives of this study were therefore to

(i) assess surface sealing and erodibility of soils in Harerge region of eastern Ethiopia by using a rainfall simulator;

(ii) explain the possible causes of sealing by comparing the physical and chemical properties of the soils with the measured erosion parameters and

(iii) investigate the potentially erodibile soils in Harerge region, eastern Ethiopia, so that further action can be suggested to combat the problem.

2.2 Materials and methods

2.2.1 Description of the study sites

A preliminary survey involving visual observation and characterization of the study sites and soil sampling at selected representative sites were carried out. A brief description of the study sites is given in (Table 2.1).

Table 2.1 Description of the study sites in Harerge, Eastern Ethiopia

Study site	Region	Zone	Geographical location	Altitude (m.)[a]	Topography (Slope gradient)	Crops	§Rainfall seasons	Major rocks	Remarks
AU Alluvial	Oromiya	East Harerge	N09°26' E42°02'	1980-2000	0-2% slope	Maize, sorghum, wheat, potato, beans, etc (Rotation)	March -mid May July-September	Granite Limestone	Dark reddish grey soils; Alemaya University research station.
AU Regosol					5-10% slope				Dark reddish brown to red; Alemaya University research station; 'Gende Je' area
AU Vertisol					0-2% slope				Very dark grey to black; Alemaya University research station
Adele			N09°23' E41°57'	2089-2100	5-10% slope	Chat, Sorghum, maize	March -mid May July-September	Granite	Coarse Reddish grey soil (about 50% rock fragments); Ridges on chat farms, Use farmyard manure, manual tillage with '‡ Dongora';
Babile			N09°13' E42°19'	1644-1655	5-10% slope	Chat, Groundnut, Sorghum	March - mid May July - September	Granite	Red soils; no free lime; Deep gullies common; Soil bunding and microbasins common for moisture conservation.
Hamaressa			N09°20' E42°04'	1994-2014	0-15% slope	Chat, sorghum, maize	March - mid May July-September	Granite Sandstone	Red soils; no free lime; Evidence of gully erosion; Soil bunding practiced; Use of DAP and Urea
Lange			N09°26-27' E41°47'	2025-2035	5-10% slope	Sorghum Potato Onion, Maize	March-end April July-September	Limestone Sandstone Granite	Black swelling soil; Lake Lange drying due to siltation; Bunds at irregular distances; Use of farm yard manure; use oxen for cultivation.
Hirna		West Harerge	N09°13' E41°05'	1828-1856	5-15% slope	Sorghum †Tef Onion	March – April July – end of Sept.	Basalt	Black swelling soils; no free lime; >50% rock fragments; Narrow V-shaped gullies; use of stone terraces; use of Farmyard manures and commercial fertilizers; Oxen for ploughing;
Chiro (Asebe Teferi)			N09°01-03' E40°50-51'	1922-2170	Up to 30% slope	Sorghum	March – mid May July – Mid Sept.	Basalt	Black swelling soils; no free lime; Use of stone terraces and bunds; Use Oxen for cultivation; 15% rock fragments;

Table 2.1 continued

Bedessa			N08°52-53' E40°46'	1687-1700	2-10% slope	Maize, chick pea, Tef, chat	March- mid May July- Mid Sept.	Limestone	Black soils; show effervescence with HCl; Bunds at 50m interval; oxen for land preparation; Use farmyard manure and commercial fertilizers; Swelling and cracking of soils;
Gelemso			N08°49' E40°32'	1786-1819	10-15% slope	Chat, maize, sorghum, Tef, sweet potato	March mid May July- mid October	Sandstones	Red soils; Ridges in chat and sweet potato farms; Use farmyard manure and commercial fertilizers
Diredawa	Diredawa	Diredawa	N09°36-37 E41°50'	1190-1195	<5% slope	Orchards, banana, papaya, vegetables	March- end May July – Sept.	Granite and Limestone	Grey loamy soil in Toni farms; Micro-basin round citrus trees; Use DAP and Urea; local 'dongora' and tractors for land preparation;
Amadle	Somali	Jijiga	N09°15' E42°59'	1726-1730	<5%	Sorghum, Maize	March – end May July - September	Limestone Sandstones	Dark colored soil; free lime; Strong wind during dry months; Grass patches and few shrubs;
Dugda Hidi (Chinaksen)			N09°22' E42°46'	1701-1715	Up to 7% slope	Sorghum, Maize	March – end May July - September	Limestone Sandstones	Red soils; free lime; Strong wind during dry months; Grass patches and few shrubs; No fertilizer use; Local people are Pastoralists
Karamara			N09°22' E42°43'	1822-1842	Sloppy land (5-15% slope)	Chat Sorghum	March – end May July - September	Limestone Sandstones Granite	Grey soils; white crusts on the surface; free lime; Strong wind during dry months; Deep gully running down Karamara hill; Acatia shrubs common; No fertilizer use; Local people are Pastoralists

§ The study sites are characterized by bimodal rainfall pattern (see appendix 4).
‡ 'Dongora' is a local manual tillage equipment
† Tef (Eragrostis tef) is a local small cereal grain crop; Chat (Catha edulis) is a common stimulant crop in the region produced for local and export markets.
[a] See appendix 3 for average altitudes of the study sites

Scale ≈1:10,000000

Fig. 2.1 Location map of Ethiopia and the study area

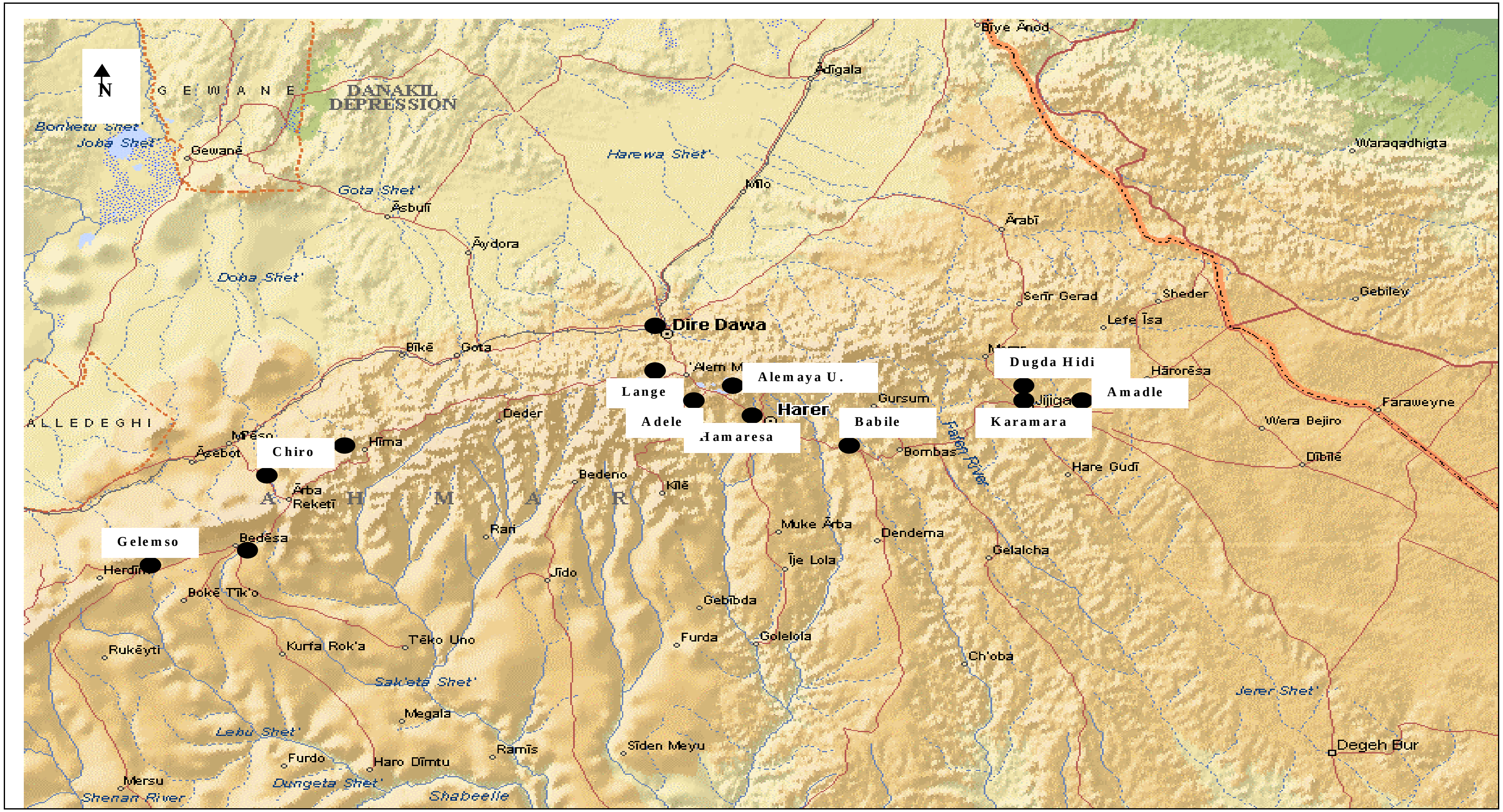

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Fig.2.2. The study sites (black dots indicate the study sites)

2.2.2 Soil sampling and analysis of some physical and chemical properties

Composite samples that represent the soils of a given study site were collected from the top 15cm for each of the study areas. The bulk of soil samples were sub-sampled, air-dried and ground to pass through a 2mm sieve before analysis of the soil in the laboratory. The specific methods for determination of the different soil properties are indicated in Table 2.2.

Table 2.2 Methods used for determination of some of the physical and chemical properties of soils.

Soil properties	**Method of determination**
Texture	Pipette method (Day, 1965)
Aggregate stability (% water stable aggregates)	Wet sieving method (Kemper and Rosenahu, 1986)
Bulk density (BD)	Clod method (Tan, 1996)
Initial water content	Gravimetric method
Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}),	1M NH_4 OAC, pH 7 method (Tan, 1996)/ Atomic absorption spectrophotometry
pH (H_2O 1: 2.5, soil: water)	Potentiometric method (Yerima et al., 1993)
Organic carbon (O.C. %)	Walkley and Black method (Schulte, 1988)
Cation exchange capacity (CEC)	1M NH_4 OAC, pH 7 method (Tan, 1996)

2.2.3 Soil packing, rainfall simulation and data acquisition

An Erosion box (pan) 554mm long, 206mm wide, and 85mm deep (Fig 2.3) was perforated at the bottom to allow free drainage. A cotton cloth was placed on the bottom to prevent soil loss through the perforated bottom. Approximately 85mm layers of soil that were air dried, crushed to pass through 4mm sieve and mixed thoroughly were packed in the box to simulate field conditions. For soils that tend to swell upon wetting, only a 75mm layer of soil was packed in the trays to reduce errors due to overflow of the soil.

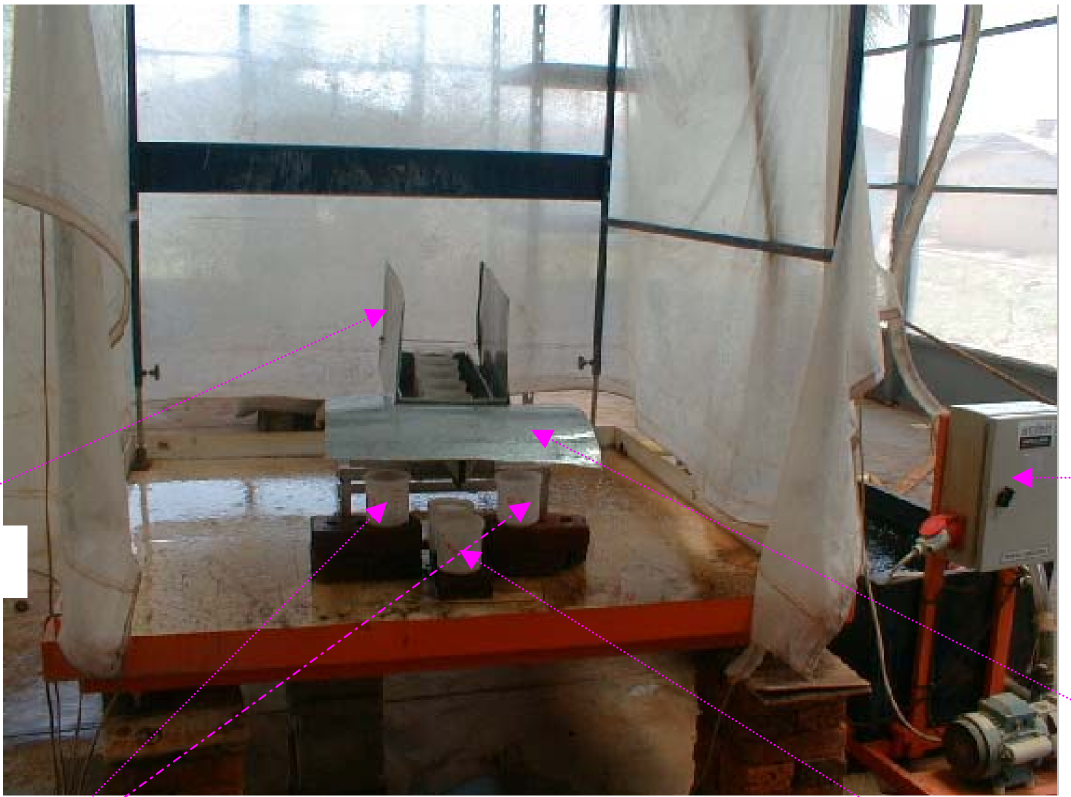


Fig. 2.3 The erosion tray and parts of the simulator system. See the position of splash, runoff and drainage collectors at the bottom of the erosion tray. The beakers on the erosion tray are meant for calibration of rainfall intensity.

A rotating disc rainfall simulator of the type described by Morin et al. (1967) was used in this experiment. 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 (60 mm/hr for this experiment), the rain was applied to the plot set at slope of 5°. The uniformity of distribution of the simulated rain on the test area was determined by measuring the volume of rain collected in beakers placed in a grid on the tray and by calculating the coefficient of uniformity using equation (2.1).

$$CU = \{100(1 - \sum \frac{/Xi - x/}{nx})\} \qquad (2.1)$$

Where, CU = Coefficient of uniformity

Xi = individual observed depth from the mean

x= Mean of observed depths

n= Number of observations

A uniformity of at least 80% were obtained and accepted. Drop diameter and size distribution was estimated using the flour pellet method (Claassens and Van der Watt, 1993). The mean diameter of raindrops was 1.9 mm; median drop velocity 6.0 ms^{-1} (estimated from calibration curve as indicated on the manual of the rainfall simulator), kinetic energy 18 $Jm^{-2}mm^{-1}$ and the height of the nozzle from the soil surface was 2.5m.

Runoff volume and the sediment suspended in it were measured at five minutes interval as soon as runoff started. Runoff was collected in plastic beakers which 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. This term sediment yield will be used in this text to describe the amount of soil washed by runoff water from the erosion tray. Water collected by the splashboards was recorded from the beginning of the rainfall simulation every five minutes. The sediment caught by the splashboards was also collected at five minutes interval. The weight of splashed sediment was determined after oven drying.

The amount of water that infiltrated into the soil was calculated as the difference between water applied to the erosion tray and water runoff from the surface of the tray including the splash volume. Runoff 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:

1. For every simulation run, a blank was obtained by taking the first reading of splash volume and subtracting it from other consecutive readings to compensate for the amount of water that falls directly on the splashboards and troughs and collected by splash collectors when rainfall is applied. This was determined with no soil in the trays.

2. The amount of rainfall (mm) was calculated by dividing the amount of water collected by the plot with the area of the plot.

3. 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 1.1) 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.

$$Q = IAt / 600 \quad \text{....................................(2.2)}$$

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

I= Intensity in mm/hr,

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

t= time elapsed since the onset of rainfall (min.) for each five minute interval.

The influence of seal formation was observed by the changes in the infiltration rates of the soils.

Special considerations

The tray used in this study does not 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 method, 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:

$$S.Y = W+\{S\,[1-(PWSA+Psa)/100]\} \qquad (2.3)$$

Where,

S.Y = Total sediment yield (kgm^{-2}),

W = Weight of wash off soil (sediment in runoff) (kgm^{-2}),

S = total weight of sediment in splash (kgm^{-2}),

PWSA = percent water stable aggregates and

Psa = percent sand.

However, the total sediment yield obtained using this equation did not comply with the actual field observations and soil properties (except the silt content which showed a significant positive correlation with the total sediment yield) determined in this study. 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 2.3 may provide reasonable information if the proportion of fine and coarse sands in the total sand fraction are known.

2.2.4. Statistical Analysis

The means of the various erosion parameters were compared among the different study sites. Correlation analysis and regression equations were performed to test the relationships between the various erosion parameters and soil properties.

2.3 Results and discussion

In this study of the erodibility of selected soils of Harerge, eastern Ethiopia, with the aid of a rainfall simulator, the relationships between various erosion parameters, infiltration characteristics and soil properties are discussed for the different soil types. The physical and chemical properties of the different soils used in this study are presented in Table 2.3.

2.3.1 Infiltration and runoff

The total amounts of infiltrated water and runoff for the different soils in this study are presented in Table 2.4. However, for the purpose of discussing the trends in the erosion parameters with increasing cumulative rainfall over time, certain soils were grouped together based on their aggregate stability and representative soils for each group were selected (Table 2.5) and used in the discussion.

The erosion parameters measured varied among the different soils. The highest total infiltration volume which was more than 70% of the total applied rainfall, was recorded on Hamaressa soils and this is followed by Bedessa, AU Regosol, AU Vertisol and Diredawa in decreasing order of magnitude (Table2.4). On the other hand, the lowest total infiltration volume was recorded for Babile, Hirna, Gelemso and Chinaksen soils in increasing order. The maximum and minimum volumes of infiltrated water during the one-hour rainfall simulation were 71% and 49% respectively of the total water applied.

Table 2.3 Some physical and chemical properties of the soils at the study sites in eastern Harerge, Ethiopia.

Sampling site	Sand ------	Silt ----%---	Clay ---------	BD Mgm^{-3}	Initial moisture %	WSA %	pH (H_2O)	OC %	CEC cmolc kg^{-1}	Exchangeable bases ($cmolc\ kg^{-1}$) K	Na	Ca	Mg	BS %	ESP	CEC Clay cmolc kg^{-1}Clay (Calculated)
Adele	36.6	20.2	43.2	1.26	5.17	66.16	7.28	0.85	28.70	0.82	0.42	1.57	1.36	14.53	1.46	60
Amadle	6.5	39.5	54.0	1.10	7.19	60.03	7.91	1.68	43.48	2.67	1.37	1.45	1.26	15.52	3.15	70
AU- Alluvial	74.6	12.7	12.7	1.42	2.91	35.50	NA	0.68	9.13	1.27	0.65	1.04	0.90	42.28	7.12	54
AU-Regosol	53.1	19.5	27.4	1.31	5.44	66.18	6.55	1.62	26.96	0.92	1.11	20.05	4.83	99.81	4.12	78
AU-Vertisol	9.6	32.6	57.8	0.99	10.43	67.28	7.64	1.25	54.78	0.99	1.34	60.60	6.33	126.43	2.45	87
Babile	76.7	14.3	9.0	1.57	1.52	33.71	6.47	0.49	3.61	0.97	0.50	1.01	0.88	93.07	13.85	21
Bedessa	5.4	28.5	66.1	1.07	8.76	71.01	7.18	1.49	55.22	0.84	0.43	1.23	1.07	6.47	0.78	76
Chinaksen	10.9	42.0	47.1	1.12	4.03	60.21	7.97	1.46	34.78	3.27	1.67	1.27	1.10	21.02	4.80	63
Chiro	NA	NA	NA	1.11	8.58	79.01	6.47	NA	NA	NA	NA	NA	NA	NA	NA	NA
DireDawa	34.8	40.5	24.7	1.48	0.84	48.94	8.78	0.51	8.70	0.87	0.44	1.05	0.91	37.59	5.06	28
Gelemso	48.9	11.3	39.8	1.35	2.92	42.19	6.60	0.69	14.35	0.69	1.03	8.19	2.25	84.74	7.18	30
Hamaresa	23.3	23.0	53.7	1.22	4.75	62.78	6.53	0.98	24.35	2.05	1.05	1.24	1.07	22.22	4.31	39
Hirna	7.8	37.0	55.2	1.09	9.54	71.23	6.56	1.61	52.61	1.25	0.64	1.27	1.10	8.10	1.22	85
Karamara	49.3	20.4	30.3	1.30	5.83	59.23	8.09	1.00	32.17	1.32	1.21	45.95	4.08	163.38	3.76	95
Lange	47.4	25.5	27.1	1.30	7.77	70.41	7.63	1.18	28.26	1.12	0.57	1.28	1.11	14.44	2.02	89

BD= Bulk density; OC= Organic Carbon; CEC= Cation exchange capacity; BS= Base saturation; ESP=Exchangeable sodium percentage; WSA = Water stable aggregates; NA = Not Available.

High runoff volume, ranging from 24.1 to 30.4mm, was recorded on Babile, Hirna, Gelemso, Chinaksen and Lange soils (Table2.4). The highest runoff volume collected during the one-hour rainfall simulation corresponds to 50.7% of the total rainfall applied. On the other hand, relatively low total runoff volumes (17.42, 18.75 and 19.06mm) were collected on Hamaressa, Bedessa and AU vertisol respectively. In terms of the total amount of rainfall applied, total runoff was less than 30% for Hamaressa soils. Other soils including Adele, Amadle, Chiro, Karamara, AU Alluvial and Dire Dawa were intermediate in their runoff volume ranging from 23.59 to 21.26mm. However, the relationship between the cause and effect is not clear. For instance, the Hirna and Lange soils, which have more than 70% water stable aggregates (Table 2.3) are not the lowest in their runoff. Therefore, it seems that no single factor is totally responsible for a given change in surface sealing and runoff but the interaction of these factors is important.

Table 2.4 Runoff and infiltrated water for the one-hour rainfall simulation runs. [Values are means of three replications].

Soil name	† Runoff		Infiltration	
	mm	Percent of rainfall	mm	Percent of rainfall
Adele	23.59	39.31	36.41	60.69
Amadle	23.40	38.99	36.60	61.01
Au Alluvial	21.70	36.16	38.30	63.84
Au Regossiol	19.06	31.77	40.94	68.23
Au Vertisol	20.95	34.91	39.05	65.09
Babile	30.39	50.65	29.61	49.35
Bedessa	18.75	31.25	41.25	68.75
Chinakssen	24.78	41.30	35.22	58.70
Chiro	23.04	38.40	36.96	61.60
Diredawa	21.26	35.44	38.74	64.56
Gelemso	25.93	43.21	34.07	56.79
Hamaressa	17.42	29.04	42.58	70.96
Hirna	27.04	45.07	32.96	54.93
Karamara	22.99	38.31	37.01	61.69
Lange	24.10	40.17	35.90	59.83

† Runoff = Sum of overland flow and splash water

Table 2.5 Soil groupings and selection of representative soils for trend analysis.

Group	Representatives	Description
Bedessa Chiro Hirna	Bedessa Hirna	Aggregate stability >70%
Amadle AU Vertisol Karamara Lange	AU Vertisol	Black soils with intermediate aggregate stability (50-70%)
AU Alluvial Babile Diredawa Gelemso	Babile Gelemso	Aggregate stability <50%
Adele AU Reogosol Chinakssen Hamaressa	AU Regosol Hamaressa	Reddish soils with intermediate aggregate stability (50-70%)

The trends of infiltration rates for the 15 soils used in this study are represented in Fig. 2.4. The highest infiltration rate throughout the simulation run was observed on soils of Hamaresa. With the exception of AU Vertisol, which has nearly attained a steady state infiltration rate at the end of the run (Fig. 2.4), infiltration rate continued to decrease, although slower but not constant towards the end of the one-hour laboratory rainfall simulation.

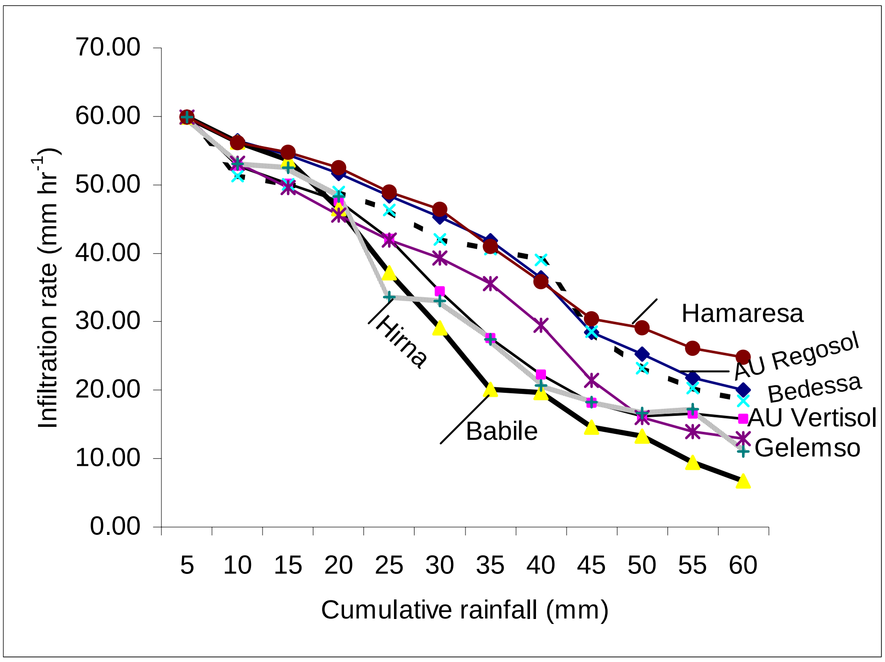


Fig 2.4 Infiltration rates (mm hr^{-1}) of selected soils over a one-hour rainfall simulation

Unlike the case for Hamaressa and AU regosol where the change in infiltration rate between the successive data points was very small, a sharp decrease in infiltration rate was observed on some soils like Babile, Hirna and Gelemso during the first 30 minutes of the run and continued decreasing with a decreasing rate thereafter. This sharp decrease in the rate of infiltration could be ascribed to surface sealing. On the contrary, the gradual decrease in infiltration rate on some soils such as Hamaressa can be attributed to the relatively higher aggregate stability.

As described earlier, the total runoff in this study was taken as the sum of overland flow and splashed water assuming that the water that has been splashed out of the plot, would have contributed to the runoff. Because of the added water splash, however, the graphs of runoff rates (Fig. 2.5) do not show the exact runoff starting time for the different soils.

Chen et al. (1980) proposed a model that divided seal formation into three stages. Stage I is from initiation of rainfall to initiation of runoff; Stage II is from initiation of runoff to steady state runoff and; Stage III is the steady state runoff. As shown in Fig. 2.4, most of the soils in this study were at stage II during the end of the one hour rainfall simulation run. The time taken from initiation of rainfall to initiation of runoff that is, stage I according to Chen et al., 1980, was different for the different soils in this study (Table 2.6). The mean earliest and latest runoff initiation times were 16.32 and 26.31 minutes which were recorded on AU Alluvial and Bedessa soils respectively. In all cases however, runoff initiation time was much more delayed than is expected under normal conditions at the rainfall intensity used in this experiment. The general delay in runoff initiation time may be ascribed to the discontinuity of rainfall for about one minute at each 5 minutes interval to collect splash and runoff. This gave some time for the water to soak into the soil increasing infiltration rate and decreasing the degree of water accumulation that would have otherwise induced early concentrated flow. In general, runoff started earlier (between 16 and 18 minutes) on AU alluvial, Amadle, Babile, Karamara and Gelemso soils. However, it started late (after 25minutes of rainfall initiation) on Bedessa, Chiro, AU Regosol, AU Vertisol and Hamaressa soils. Most of the information collected in this study support that soils on which runoff started earlier are relatively more prone to sealing than those on which runoff initiation time was delayed (compare Tables 2.4 and 2.6).

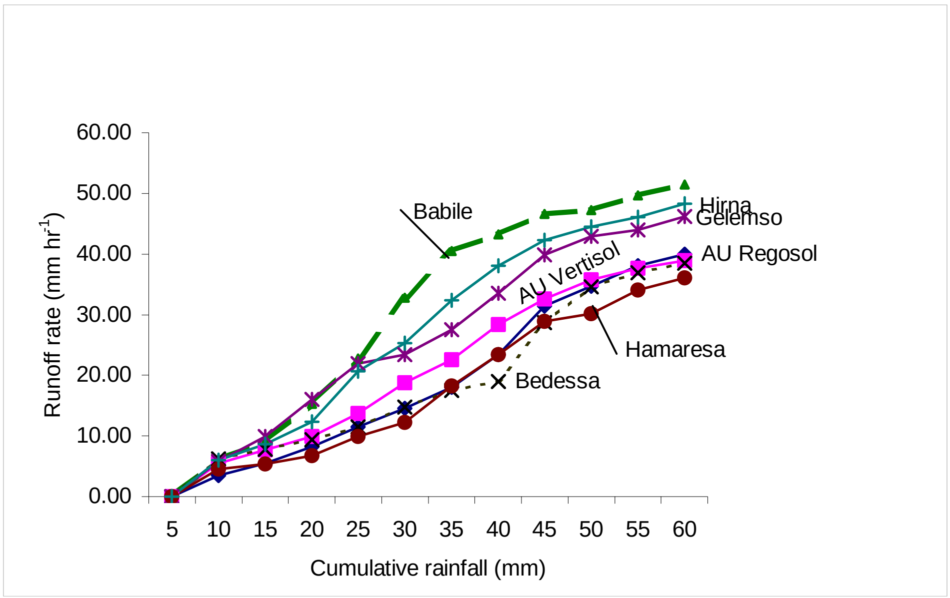


Fig.2.5 Runoff rates for selected soils during a one-hour simulated rainfall.

For the majority of the soils, runoff increased immediately after its initiation until some peak point after which the rate of increase decreased with further rainfall application. The earliest rapid increase in runoff was observed on Babile soils at about 25 minutes of the run (Fig. 2.5). The runoff rate for AU Regosol, Bedessa, and Hamaressa soils was very low until it received 30mm of rainfall after which it showed a rapid increase until it slowed down after 50 minutes. This can be attributed to the slower rate of sealing in these soils.

Differences in runoff rates among the soils are attributed to differences in the rate of seal formation (Singer and Le Bissonnais, 1998). This experiment suggests that the Babile, Hirna, Gelemso, Chinaksen and Lange soils formed seals earlier than other soils and this resulted in low infiltration rate and high runoff. A close observation of the soil properties reveals that the low final infiltration rate and high runoff in these soils is mainly associated with their exchangeable sodium percentage (ESP). Among the soils where high runoff was observed, Babile and Gelemso have the highest ESP and low aggregate stability (Table 2.3). Therefore, runoff was positively correlated with ESP (r = 0.50) and negatively correlated with final infiltration rate (r = -0.72).

The reason for the high runoff with Hirna and Lange soils which have reasonably high aggregate stability (71.23% and 70.41% respectively) and low ESP (1.22 and 2.02 respectively) is not clear.

Table 2.6 Mean time taken from initiation of rainfall to initiation of runoff and drainage in a laboratory rainfall simulation study at 60mmhr^{-1} rainfall intensity.

	Mean time to runoff initiation (Min.sec)	Mean time to drainage initiation (Min.sec)
Adele	24.45	43.52
Amadle	16.47	59.56
AU Aluvial	16.32	38.15
AU Regosol	25.03	31.17
AU Vertisol	25.01	33.00
Babile	17.08	30.04
Bedessa	26.31	32.32
Chinaksen	19.19	45.04
Chiro	25.31	36.34
Diredawa	24.10	34.11
Gelemso	18.04	41.11
Hamaresa	26.02	39.05
Hirna	20.28	34.01
Karamara	17.58	60.00
Lange	21.34	38.2

It is however, important to note that more significant correlation was obtained between the soil properties and overland flow than when total runoff (splash volume plus overland flow) is considered. Overland flow was significantly correlated with aggregate stability (r = -0.81), organic carbon (r = -0.63), ESP (r = 0.80), clay content (r = -0.61) and initial moisture content (r = -0.66) all of which are interrelated. This can be ascribed to the interactive effect of these soil properties on aggregate stability thereby affecting surface sealing which has more direct effect on overland flow than splash water.

2.3.2 Splash detachment and sediment yield

The final rates of splash and sediment yield as well as the total masses for the soils considered in this study are presented in Table 2.7. The final rates of soil splash and sediment yield ranged from 0.37 and 0.08 kg $m^{-2}hr^{-1}$ to 1.23 and 0.32 kg $m^{-2}hr^{-1}$ respectively, but these figures must be considered only as relative values as they are dependent on experimental techniques employed. The total splash and sediment yield followed more or less similar trend with runoff. The highest splash erosion was recorded on Babile (1.143 kg m^{-2}) which was followed by Gelemso (0.965 kg m-2) and Diredawa (0.951 kg m^{-2}). Sediment yield was also relatively higher on Gelemso (0.114 kg m^{-2}), Babile (0.10 kg m^{-2}) and Diredawa (0.09 kg m^{-2}) soils than on others. Hamaressa, Lange, AU regosol, Adele and Amadle had relatively lower (less than 0.060 kg m^{-2}) sediment yield as compared to other soils studied in this experiment.

Table 2.7 Mean final splash and sediment yield rates and total splash and sediment yield masses for replicated one-hour rainfall simulation runs.

Soil name	Splash erosion		Sediment yield	
	Final rate	Total mass	Final rate	Total mass
	Kg $m^{-2}hr^{-1}$	Kg m^{-2}	Kg $m^{-2}hr^{-1}$	Kg m^{-2}
Adele	0.53	0.74	0.09	0.06
Amadle	0.93	0.51	0.09	0.06
Au Alluvial	0.89	0.59	0.24	0.08
Au Regossiol	1.08	0.87	0.15	0.06
Au Vertisol	0.73	0.64	0.17	0.05
Babile	1.13	1.14	0.27	0.10
Bedessa	0.92	0.65	0.24	0.06
Chinakssen	0.81	0.67	0.17	0.07
Chiro	0.98	0.73	0.13	0.07
Diredawa	0.99	0.95	0.15	0.09
Gelemso	1.23	0.97	0.32	0.11
Hamaressa	1.03	0.82	0.09	0.05
Hirna	0.71	0.61	0.16	0.06
Karamara	0.37	0.59	0.13	0.07
Lange	0.67	0.68	0.08	0.06

Sediment yield rates for some of the 15 soils were presented in Fig. 2.6. On Babile and Gelemso soils, a sharp increase in sediment yield rates was observed both during the early initiation of runoff and late around the end of the one hour simulation run with a more or less higher rate than other soils. As explained earlier, the high detachment rate indicated by large flow detachment and splash detachment on these soils is due to their relatively low aggregate stability and infiltration rate which is mainly resulted from their high ESP and low OC contents (Table2.3). Hence, the soil particles from the broken aggregate are easily detached and transported by the splashing and running water.

For soils like Hamaressa, sediment yield rate has attained its steady state after 30 minutes and was the lowest during the final stages of the simulation run.

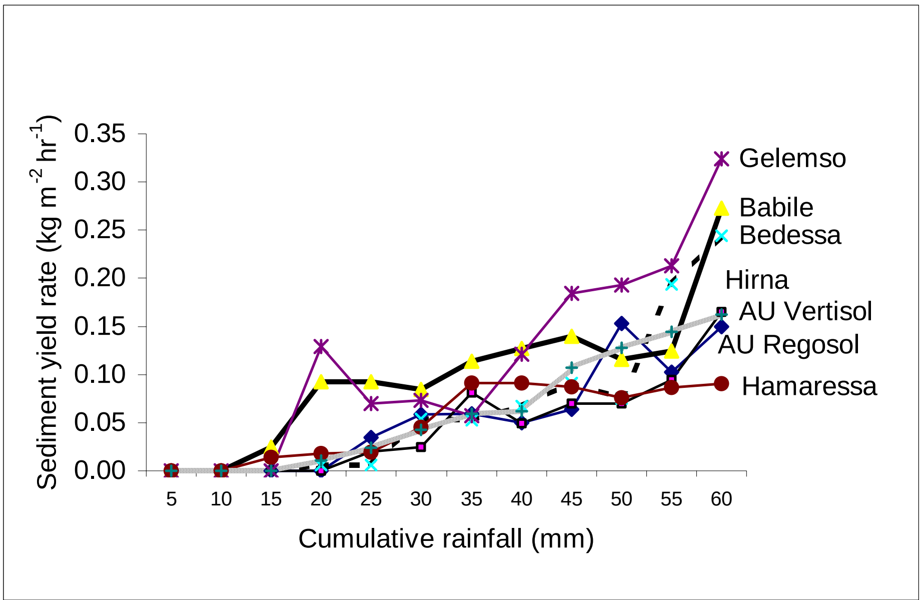


Fig.2.6 Sediment yield rate vs. cumulative rainfall during a one-hour rainfall simulation on selected soils.

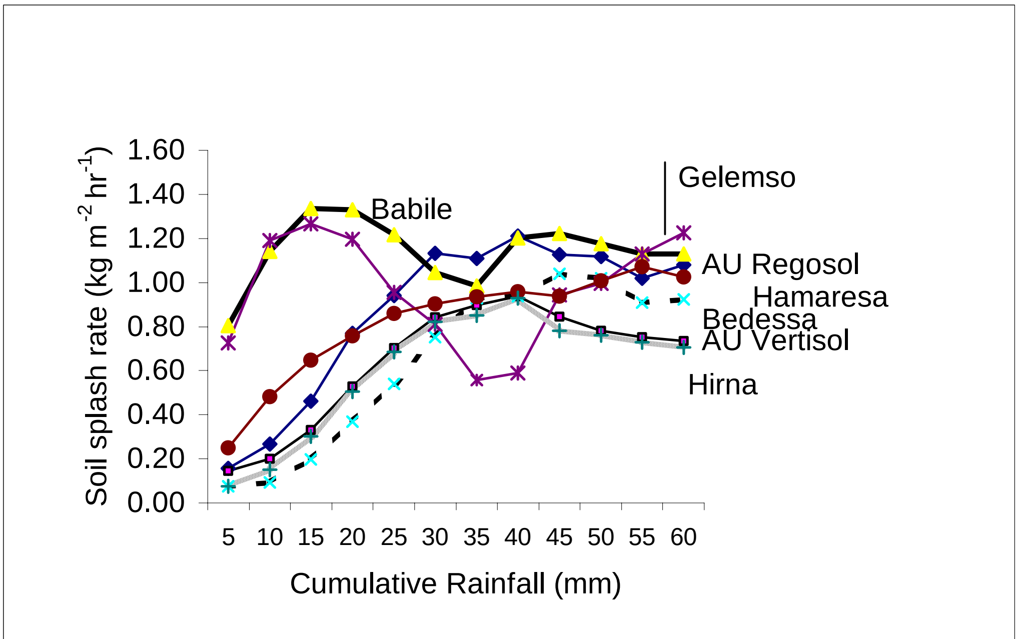


Fig. 2.7 Soil splash rate (kg m^{-2} hr^{-1}) vs. cumulative rainfall during a one-hour rainfall simulation on selected soils

The trend of soil splash rate versus cumulative rainfalls for the seven representative soils is presented in Fig 2.8. Babile and Gelemso attained their highest soil splash rates during the first 15 minutes of the rainfall event after which the rate decreased sharply especially for Gelemso (until it becomes the lowest of all) and started to raise again towards the end of the one-hour simulation. The high soil splash erosion rate during the early stages of the run on Gelemso and Babile soils is due to their weak aggregate stability and their susceptibility to detachment by raindrop impact. However, the reduction in their rate of soil splash at the middle of the simulation run (Fig.2.7) can be associated with removal of detached soil particles during the earlier runs as well as increase in shear strength (Bradford et al., 1987) of the soil due to sealing. But with a continued application of rainfall, the rate of splash started to rise mainly because of the removal of the surface seals by runoff and exposure of the underlying unsealed soil to rainfall impact.

For other soils including Hirna, AU vertisol and Bedessa, the rate of soil splash increased gradually up to about 40 minutes of the simulation period and declined thereafter. This can be explained by a gradual breakdown of the relatively strong soil aggregate and their relatively low tendency to sealing at early rainfall periods.

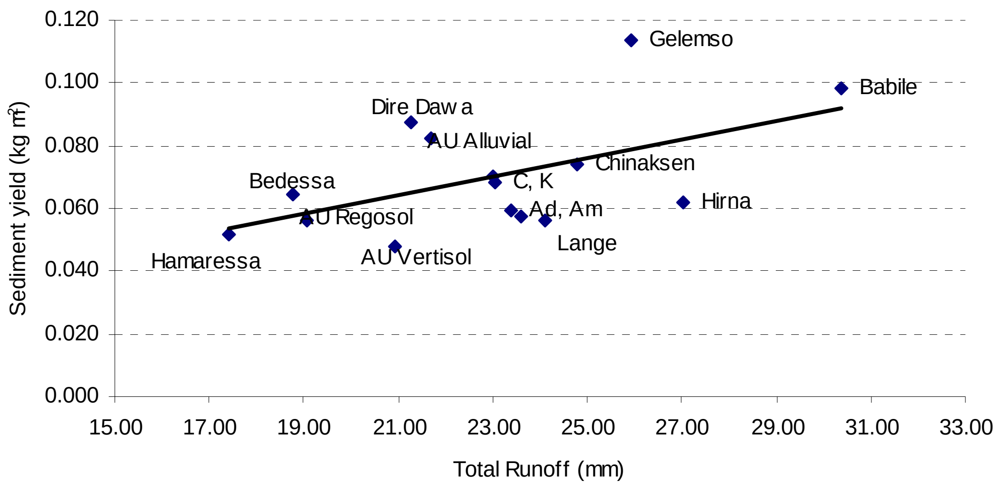
2.3.3 Relationships between runoff, splash detachment and sediment yield

Though not as high as expected, there is a significant linear relationship between total sediment yield and runoff ($r = 0.54$) (see Fig. 2.8), and total sediment yield and splash weight ($r = 0.61$). Working on seven soils of the Mediterranean climate, Singer and Le Bissonnais (1998), also reported a similar highly significant linear relationships between mass of soil eroded and total runoff ($r^2 = 0.629$). Such linear relationships between runoff and soil loss has also been reported in other studies (eg. Feleke, 1987; Mullugeta, 1988; Bobe and Gachene, 1999; Sonneveled et al., 1999)

Seal formation affects soil erosion in different ways. Surface sealing reduces infiltration rate and increases runoff (Bradford et al., 1987) thereby increasing detachment and transport of soil particles by concentrated flow. On the other hand, some reports indicate that crusting increases the resistance of the soil to detachment resulting in low sediment loss (Bradford et al., 1986; Sharma, 1996; Bajracharia and Lal, 1999). The fact that high splash weight was collected on soils with high runoff in this study is not in line with the above explanation. This could be attributed to the soil properties which are too unstable to form strong seals that can resist the impact of raindrops despite reduced infiltration rate due to clogging up of pore spaces by the dispersed soil particles. It could also be associated with the particle and aggregate sizes of the soils.

On the other hand, Hirna and Amadle soils have reasonably high runoff (27.04 and 23.40 mm respectively) but have a relatively low splash weight (0.608 kg m^{-2} and 0.514 kg m^{-2} respectively). This could be explained by the second effect of sealing where it increases the resistance of the soils to detachment due to the coherence of soil particles during the sealing process. It could also be associated with formation of temporary water ponding on the plots that may increase the gap between the impacting raindrops and the soil surface (Palmer, 1963 quoted by Bradford and Huang, 1996; Sharma, 1996) resulting in low sediment availability in the splashing water.

The total soil loss (sum of splash and sediment yield) also followed the same trend with runoff especially for the most vulnerable soils. Babile and Gelemso are the most erodible.



[Ad= Adele; Am= Amadle; C = Chiro; K= Karamara]

Fig. 2.8 Total sediment yield (kg m^{-2}) vs. total runoff for a one hour rainfall simulation on the studied soils.

In general, the absolute values (0.5 to 1.1 t ha^{-1}) of sediment yield collected in this laboratory rainfall simulation experiment for the different site are very low. This could be mainly due to the short slope length of the small erosion plots which are responsible for the low flow velocity of runoff and low shearing force resulting in less detachment and transport of soil. Most of the soil detachment in this laboratory rainfall simulation study is associated with the impact of raindrops. This is indicated by much higher splash weight than sediment yield for each soil considered. Therefore, the sediment yield and splash detachment values should only be considered as relative figures. Under normal field conditions, overland flow rates play a significant role in detaching and transporting sediments due to the high velocity of a concentrated flow in channels and rills.

2.3.4 Relationships between soil properties and erosion parameters

Regression equations and correlation coefficients between the total runoff, sediment yield and splash weight versus some soil properties are presented in Table 2.8. Total runoff is positively correlated with ESP (r = 0.50) negatively correlated with aggregate stability (r = -0.40) though none of them are significant.

However, the correlation coefficients indicated in these study should be interpreted with much care. When the effect of one factor or soil property on a given erosion parameter is discussed, attention should also be given to the interaction effects of the other factors. A positive correlation between a given soil property and erosion parameter doesn't always imply a cause and effect relationship. For instance, a significant positive correlation was observed between bulk density and runoff volume (r = 0.70). But this alone won't lead us to a general conclusion that soils with high bulk density will have high runoff. As a matter of coincidence, those soils with relatively high sand content like Babile in this study, are characterized by high ESP and low aggregate stability. Otherwise, in most cases, soils with high sand content and consequently high bulk density are expected to have high infiltration rate and low runoff. Besides, as this study is limited by less number of data points due to time and financial constraints, the correlation coefficients obtained between the various soil properties and erosion parameters should be interpreted with much care.

Table 2.8 Regression equations and correlation coefficients between selected soil properties and erosion parameters of some soils in eastern Ethiopia

Erosion parameter (Y)	Soil Property (X)	Regression equations	Correlation coefficient (r)
Sediment yield (kg m^{-2})	Clay (%)	Y= 0.0885 - 0.0006X	-0.68*; n=13
	OC (%)	Y= 0.1026 – 0.0294X	-0.65*; n=14
	ESP	Y= 0.0529 + 0.0041X	0.72**; n=14
	WSA (%)	Y=0.1322 - 0.001X	-0.77**; n=14
Splash weight (kg m^{-2})	Clay (%)	Y= 1.0601 – 0.0074X	-0.0.67*; n=13
	OC (%)	Y = 1.0344 – 0.2622X	-0.62*; n=14
	ESP	Y=0.5804 + 0.0375X	0.71**; n=14
	WSA (%)	Y=0.9695 – 0.0408X	-0.78**; n=13
Runoff (mm)	WSA (%)	Y = 29.289 – 0.0408X	0.4^{ns}; n=14
	ESP	Y = 20.675 + 0.5208X	0.5^{ns}; n=14

*= Significant at (P=0.05); **= Significant at (P=0.01); ns = Not significant at (p=0.05); n = number of observations

Total sediment yield is positively correlated with ESP (r = 0.72) but negatively correlated with %Clay (r = -0.68), percent organic carbon (r = -0.65), initial moisture content (r = -0.73) and aggregate stability (r = -0.77) all correlation being significant at 5 % probability level. The positive linear relationship obtained between total sediment yield and sand content and bulk density in this experiment is also mainly associated with the high ESP of the coarse textured soils. The result would have been different if the soils were uniform in their ESP but vary only in texture; because various studies (including Trott and Singer, 1983; Obi et al., 1989; Merzoak and Blake, 1991) reported a negative relationship between sand content and erosion rate.

The negative correlation between sediment yield and other soil properties like clay content, organic carbon content, CEC, initial moisture content and aggregate stability is mainly attributed to the aggregating and stabilizing effect of clay and organic matter on soil particles. All these soil properties are interrelated and the effects are expressed through their effect on aggregate stability and in turn on the erosion parameters. The aggregate stability of the soils (aggregate sizes 0.5 – 2mm) at the study sites is presented in Fig. 2.9 and the relationships between aggregate stability and major erosion parameters is presented in Fig. 2.10. High CEC, initial moisture content and high percentage of water stable aggregates are all functions of high clay and organic matter contents.

Splash erosion is positively and significantly correlated with % sand (r=0.72), bulk density (r = 0.82), and ESP (r = 0.71), but negatively correlated with %clay (r = -0.67), %OC (r = -0.62), CEC (r = -0.88), initial moisture content (r = -0.67) and aggregate stability (r = -0.78).

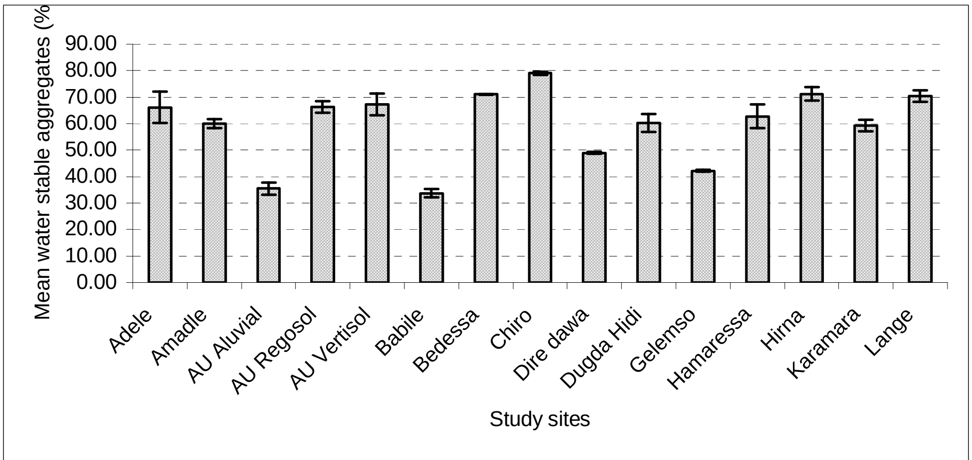


Fig. 2.9 Aggregate stability values for the soils of the study sites. [Y-error bars indicate standard deviations]

The positive correlation among aggregate stability, clay content, organic matter content and CEC and the negative correlation between these soil properties and erosion parameters indicate that these soil properties are the most influential in reducing runoff and soil loss. Similar positive linear relationship between aggregate stability and other soil properties such as clay content and organic matter content has also been reported in several studies (Kemper and Kotch, 1966; Goldenberg et al., 1988; Shainberg et al, 1997).

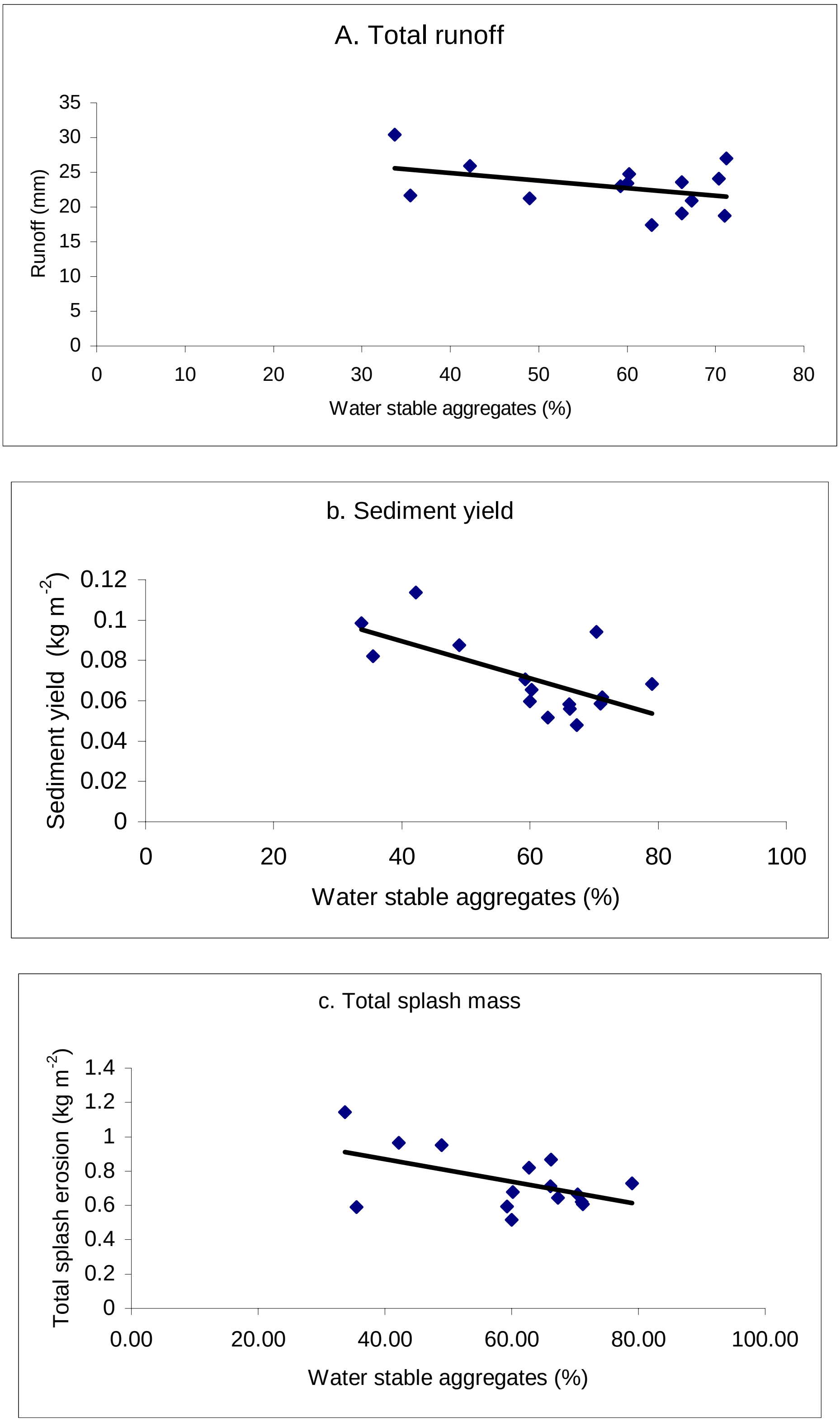


Fig. 2.10 Relationships between percent water stable aggregates and total (a) runoff, (b) sediment yield, and (c) splash weight

Gollany et al. (1991) also found that aggregate stability increases with clay content. Similarly, Le Bissonnais, 1988 (quoted by Le Bissonnais, 1996) also reported an increase in aggregate stability (%>0.2mm) with increasing CEC and clay content. However, with a wider range of soils, Le Bissonnais and Singer (1993) as well as Pierson and Mulla (1990) didn't find significant correlations between clay content and aggregate stability. This may be associated with variations in the types of the clay.

On the other hand, the fact that soil properties such as percent sand, bulk density and ESP, that are negatively correlated with aggregate stability, have all positive linear relationships with runoff, sediment yield, and splash detacment, is mainly attributed to the overwhelming effect of high ESP on reducing aggregate stability and increasing runoff and soil erosion due to surface sealing. Several studies (Agassi et al., 1981; Singer et al., 1982; Shainberg and Latey, 1984) also reported that increase in ESP caused more dispersion, crust formation and erosion though the effect varied among different soils (Le Bissonnais, 1996). Some soils are affected at very low ESP, others are affected only at high ESP and some are not affected at all. Levy and Van der Watt (1988) found that dispersion of a Kaolinitic soil was not significantly affected in the ESP range of 1% to 9% while two other soils (i) with mixed kaolinitic, illite and monmorilonite and (ii) with illite and interstratified minerals were significantly affected at ESP of 4.3%. The ESP of our soils in this study is in the range of 0.78 for Bedessa to 13.85 for Babile (Table 2.3) and an apparent negative linear relationship between ESP and aggregate stability is shown (Fig. 2.11).

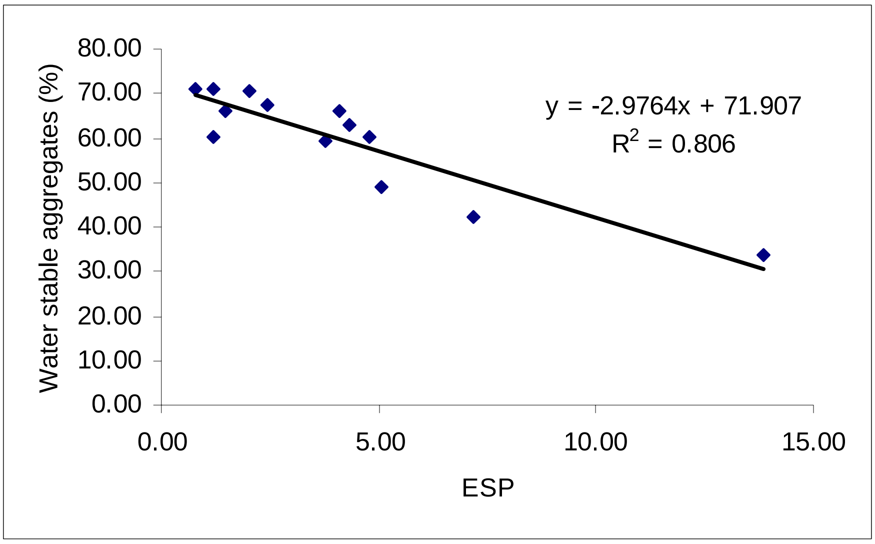


Fig. 2.11 The relationship between aggregates stability and ESP of the soils in the study areas.

2.4 Conclusion

Soil erodibility assessment of selected Harerghe soils under laboratory rainfall simulation indicate that different soils have different tendencies to seal formation, runoff and soil loss. Soil erodiblity in this study refers to the measure of the combined effect of sediment and splash loss after one hour of rainfall simulation. Soils of Babile, Gelemso, and Diredawa are found to be more susceptible to surface sealing and are more prone to splash detachment and sediment yield. This was mainly attributed to their relatively high ESP and subsequent low aggregate stability and low infiltration rate which led to high runoff and soil loss. The soils which were found to be relatively resistant to erosion such as Hamaressa, Bedessa, Au Regosol and AU vertisol were characterized by high aggregate stability and most of them have high % clay, % organic matter and CEC but low ESP.

In general, although there is some indication that the majority of the soils with low organic matter content, clay, CEC, and water stable aggregates were more erodible than those having relatively high content of these soil properties, no single soil property was found to affect soil erodibility independently. The interaction effect of the soil properties on erosion parameters may complicate the relationship. Besides, some other important soil properties (like clay mineralogy, CBD extractable Fe and Al) which are not determined in this study but are reported to have a significant effect in soil aggregate stability might also had a hidden effect on the erosion parameters of these soils. Therefore, the reason for high or low erodibility of a given soil under a specific slope and rainfall characteristics is a function of the interaction of its physical and chemical properties and hence, is different for different soils.