Evaluation of soil erosion in the Harerge region of Ethiopia using soil loss models, rainfall simulation and field trials

by

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ACRONYMS AND ABBREVIATIONS USED

ACRU	Agricultural Catchments Research Unit
ANOVA	Analysis Of Variance
ASA	American Society of Agronomy
ASAE	American Society of Agricultural Engineering
AU	Alemaya University
BD	Bulk Density
CEC	Cation Exchange Capacity
CSSA	Crop Science Society of America
ESP	Exchangeable Sodium Percentage
FAO	Food and Agriculture Organization
IAHS	International Association of Hydrological Sciences [formerly International Association of Scientific Hydrology, Netherlands]
IITA	International Institute for Tropical Agriculture
IR	Infiltration Rate
ISCO	International Soil Conservation Organization
ISCW	Institute for Soil, Climate and Water
MOA	Ministry Of Agriculture
MOMS	Modular Optoelectronic Multi-Wavelength Scanner
NH_4OAC	Ammonium Acetate
OC	Organic Carbon
ODU	Old Dominion University [Norfolk, Virginia, US]
RUSLE	Revised Universal Soil Loss Equation
SADC	Southern African Development Community
SADCC	Southern African Development Coordination Conference
SAS	Statistical Analysis System
SCRP	Soil Conservation Research Project
SFSCDD	Community Forest and Soil Conservation and Development main Department
SLEMSA	Soil Loss Estimation Model for Southern Africa

SSSA	Soil Science Society of America
UNEP	United Nations Environmental Program
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
WSA	Water Stable Aggregates

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Abstract

Accelerated soil erosion is one of the major threats to agricultural production in Ethiopia and the Harerge region is not exceptional. It is estimated that about 1.5 billion tones of soil is being eroded every year in Ethiopia. In the extreme cases, especially for the highlands, the rate of soil loss is estimated to reach up to 300 t $ha^{-1}yr^{-1}$ with an average of about 70 t $ha^{-1}yr^{-1}$ which is beyond any tolerable level. The government have made different attempts to avert the situation since 1975 through initiation of a massive program of soil conservation and rehabilitation of severely degraded lands. Despite considerable efforts, the achievements were far bellow expectations.

This study was aimed at assessing the effect of some soil properties, rainfall intensity and slope gradients on surface sealing, soil erodibility, runoff and soil loss from selected sites in the Harerge region, eastern Ethiopia, using simulated rainfall. Soil loss was also estimated for the sites using Soil Loss Estimation Model for Southern Africa (SLEMSA) and the Universal soil Loss Equation (USLE). Moreover, the effectiveness of various rates and patterns of wheat residue mulching in controlling soil loss was also evaluated for one of the study sites, (i.e. Regosol of Alemaya University), under both rainfall simulation and field natural rainfall conditions.

For most of the erosion parameters, the interaction among soil texture, slope gradient and rainfall intensity was significant. In general however, high rainfall intensity induced high runoff, sediment yield and splash. The effect of slope gradients on most of the erosion parameters was not significant as the slope length was too small to bring about a concentrated 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.

The soils form the 15 different sites in Harerge showed different degrees of vulnerability to surface sealing, runoff and sediment yield. These differences were associated with various soil properties. Correlation of soil properties to the erosion parameters revealed that aggregate stability was the main factor that determined the susceptibility of soils to sealing, runoff and soil loss. This was in turn affected by organic carbon content, percent clay and exchangeable sodium percentage (ESP). Soils with relatively high ESP such as those at Babile (13.85) and Gelemso (7.18) were among the lowest in their aggregate stability (percent water stable aggregates of 0.25 –2.0mm diameter); and have highest runoff and sediment yield as compared to other soils in the study. Similarly, most of those soils with relatively low ESP, high organic carbon content (OC%) and high water stable aggregates such as Hamaressa, AU (Alemaya University) vertisol and AU regosol were among the least susceptible to sealing and interrill erosion. Nevertheless, some exceptions include soils like those of Hirna where high runoff was recorded whilst having relatively high OC%, low ESP and high water stable aggregates.

Both the SLEMSA and USLE models were able to identify the erosion hazards for the study sites. Despite the differences in the procedures of the two models, significant correlation (r = 0.87) was observed between the values estimated by the two methods. Both models estimated higher soil loss for Gelemso, Babile, Karamara and Hamaressa. Soil loss was lower for Diredawa, AU-vertisol and AU-Alluvial all of which occur on a relatively low slope gradients. The high soil loss for Babile and Gelemso conforms with the relative soil erodibility values obtained under rainfall simulation suggesting that soil erodibility, among others, is the main factor contributing to high soil loss for these soils. The difference in the estimated soil losses for the different sites was a function of the interaction of the various factors involved. Though the laboratory soil erodibility values were low to medium for Hamaressa and Karamara, the estimated soil loss was higher owing to the field topographic situations such as high slope gradient.

SLEMSA and USLE showed different degrees of sensitivities to their input variables for the conditions of the study sites. SLEMSA was highly sensitive to changes in rainfall kinetic energy (E) and soil erodibility (F) and less sensitive to the cover and slope length factors. The sensitivity of SLEMSA to changes in the cover factor was higher for areas having initially smaller percentage rainfall interception values. On the other hand, USLE was highly sensitive to slope gradient and less so to slope length as compared to the other input factors.

The study on the various rates and application patterns of wheat residue on runoff and soil loss both in the laboratory rainfall simulation and under field natural rainfall conditions revealed that surface application of crop residue is more effective in reducing soil loss and runoff than incorporating the same amount of the residue into the soil. Likewise, for a particular residue application method, runoff and soil loss decreased with increasing application rate of the mulch. However, the difference was not significant between 4 Mg ha^{-1} and 8 Mg ha^{-1} wheat straw rates suggesting that the former can effectively control soil loss and can be used in areas where there is limitation of crop residues provided that other conditions are similar to that of the study site (AU Regosols). The effectiveness of lower rates of straw (i.e. less than 4 Mg ha^{-1}) should also be studied. It should however be noted that the effectiveness of mulching in controlling soils loss and runoff could be different under various slope gradients, rainfall characteristics and cover types that were not covered in this study.

Integrated soil and water conservation research is required to develop a comprehensive database for modelling various soil erosion parameters. Further research is therefore required on the effect of soil properties (with

special emphasis to aggregate stability, clay mineralogy, exchangeable cations, soil texture and organic matter), types and rates of crop residues, cropping and tillage systems, mechanical and biological soil conservation measures on soil erosion and its conservation for a better estimation of the actual soil loss in the study sites.

Keywords: Erosion models, Infiltration rate, mulching, rainfall intensity, rainfall simulator, runoff, sediment yield, SLEMSA, slope gradient, soil properties, splash, surface sealing, texture, USLE, water stable aggregates

INTRODUCTION

It is widely recognized that accelerated erosion is one of the major factors responsible for soil degradation (Dudal, 1982; Kovda, 1983; Lal, 1990; 1994; Piccolo et al., 1997). Mismanagement, neglect and exploitation can ruin the fragile resource and become a threat to human survival (Lal and Pierce, 1991). Brown et al. (1990) estimated that the world could be losing 14 million tons of grain output because of environmental degradation, mainly due to soil erosion. According to Dudal (1981), the rate of agricultural degradation world wide by soil erosion and other factors is leading to an irreversible loss in productivity in about six million hectares of fertile land a year. Buringh (1981) estimated the annual global loss of agricultural lands due to soil erosion to be about 3 million hectares. Crop productivity is reduced to zero or becomes uneconomic because of soil erosion or erosion induced degradation on about 20 million hectares every year (UNEP, 1991) in the world. According to Kovda (1983), soil erosion has destroyed about 430 million hectares of productive lands since the beginning of settled agriculture. Human induced soil degradation has affected 24 % of the inhabited land area of the world. The values for the individual continents range from 12% in North America, 18% in South America, 19% in Oceania, 26 % in Europe, 27% in Africa and 31% in Asia (Oldeman, 1991-92).

Despite a wide recognition of accelerated erosion as a serious global problem, assessing the dimensions like: the magnitude, extent and the rate of soil erosion and its economic and environmental consequences precisely and reliably however, is still difficult (Lal, 1988, 1994). Besides, the readily available information in the literature is often based on reconnaissance surveys and extrapolations based on sketchy data.

Ethiopia has a total surface area of 111.8 million hectares; of which 60 million hectares are estimated to be agriculturally productive. Out of the estimated agriculturally productive lands, about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return; with an estimated total loss of 2 billion m^3 of top soil per year (Fikru, 1990; Sertsu, 2000). According to the Soil Conservation Research Project (SCRP, 1985) of Ethiopia, the rate of soil loss in extreme cases ranges from 0 to 300 t $ha^{-1}yr^{-1}$ with an average loss (observed from SCRP experiments conducted in six different agro-climatic regions namely Maybar, Gununo, Hunde Lafto, Andit Tid, Anjeni and Dizi) of 70t $ha^{-1}yr^{-1}$, which is beyond the concept of any tolerable soil loss. This SCRP project also estimated that about 1.5 billion tones of soil are eroded away every year in Ethiopia.

The Ethiopian government first recognized the impact of soil degradation after the 1973-74 famine. Since then, it initiated a massive program of soil conservation and rehabilitation in the highly degraded areas (Hurni, 1985) which involved the mobilization of peasant associations and the involvement of over 30 million peasant workdays per year. Reports indicate that, between 1975 and 1989, terraces were built on 980000 hectares of cropland; 208000 hectares of hillside terraces were constructed and 310000 hectares of highly denuded lands were revegetated (Kruger et al., 1996). Yet these achievements are far bellow expectations, and despite considerable efforts, the country is still losing an appreciable amount of precious topsoil annually.

Sustainable soil management systems must be developed to reduce further degradation and restore the productivity of the eroded land. Lal and Pierce (1991) suggested that the scientific community must develop agricultural technology to: (a) reduce input while maximizing economic returns, (b) decrease soil degradation, (c) minimize risks of pollution of natural waters and environments, (d) restore productivity of degraded land and (e) maintain productive capacity of existing land by preserving a soil's life support processes.

Two soil conservation approaches, the barrier approach and the cover approach, have been developed and are in use world wide to control soil loss by water erosion (Young, 1989). Soil conservation methods including terraces, channels (bunds) and stonewalls as well as semi-permeable structures like grass strips and hedgerows are used as barriers to obstruct runoff and sediment carried with it. The cover approach usually involves use of plant materials and others like stones, plastics and industrial wastes, to obstruct raindrops beating of the soil surface and reduce the flow volume and velocity of runoff.

Although the two approaches are not alternative but complementary (Hudson, 1984), the fact that most of the physical or mechanical structures like terraces and channels that involve land shaping and manipulation, are expensive (Rodriguez, 1997) and time consuming (Tripathi and Singh, 1993) and deserve careful thought and planning, makes the use of the cover approach very important under farmers' conditions. Surface mulching with crop residues is found to be one of the most cost effective means of erosion control (Shelton et al., 1995).

Therefore, this study emphasizes on some factors affecting soil erodibility; estimates erosion hazard using some empirical soil loss models; and evaluates the role of different rates and patterns of surface cover materials (mulches) on control of erosion.

The specific objectives are outlined below:

- To assess the erodibility of some soils of Harerge, eastern Ethiopia, under laboratory rainfall simulation and relate erodibility to the physico-chemical properties of the soils.
- To study the effect of soil texture on seal formation, infiltration, runoff and soil erosion under different rainfall intensities on various slope gradients.
- To predict soil loss in the study areas using the SLEMSA and USLE models and correlate the predicted soil loss and measured soil erodibility.
- To study the effect of surface application and incorporation of different rates of crop residues on seal formation, infiltration, and runoff and soil loss under different rainfall intensities using laboratory rainfall simulation.
- To investigate the role of rates and application methods of straw mulches on runoff and soil loss from field plots using natural rainfall.

To achieve the above objectives, the research involved a preliminary survey of the study sites and soil sampling. Erodibility of the soils collected from the different areas of the region was assessed in the laboratory under rainfall simulation. The effect of some soil properties, slope and rainfall intensity on soil surface sealing and erosdibility was also evaluated. Moreover, soil loss was estimated for the various study sites using the USLE and SLEMSA models. The role of various rates and application methods of straw mulches on soil erosion control was assessed under both laboratory rainfall simulation and natural rainfall in field experimental plots.