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Full Length Research Paper

Soil loss prediction using USLE and MUSLE under conservation tillage integrated with '*fanya juus*' in Choke Mountain, Ethiopia

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Conservation tillage is an important strategy for the adoption of soil and water conservation and to reduce runoff and soil loss by water erosion. This study was undertaken to validate USLE/MUSLE as affected by integration of conservation tillage with '*fanya juus*' at Enerata kebele, East Gojjam of Amhara Region. Runoff and soil loss were collected from 38 storm events through isolated trenches for calibration and validation of the models. Input variables required by USLE and MUSLE models mainly rainfall erosivity, soil erodibility, topography of the land, land use and crop management factors were obtained from field measurements. The results showed that both models underestimated soil loss. On average, the efficiency of MUSLE model was 71.5% while that of USLE was 53.5%. This was due to the runoff which was considered as an input for MUSLE model. Runoff was found to be a better indicator than rainfall for soil loss prediction. Overall, the MUSLE model was good to estimate soil loss and to plan different soil conservation programs.

Key words: Conservation tillage, fanya juus, MUSLE, soil loss, USLE.

INTRODUCTION

Accelerated soil erosion by water has been a major threat to crop production in Ethiopia (Hurni, 1993; Sutcliffe, 1993; Tamene, 2005). Some soil erosion models estimated soil loss in Ethiopia to be as high as 1.5 billion tons yr^{-1}, of which more than 10 tons ha^{-1} y^{-1} was from cultivated fields, which was beyond the tolerable soil loss limit (SCRP, 1985). FAO (1986) also reported that some 50% of the highlands of Ethiopia are already significantly eroded and erosion caused a decline in land productivity at the rate of 2.2% per year. The study also predicted that by the year 2010, erosion could reduce per capita incomes of the highland population by 30%. To overcome the problem, the government has been mobilizing communities and resources for the construction of physical soil and water conservation structures since 1970's. However, excess runoff puts extra pressure on the structures leading to breaching and accelerates soil erosion downstream. The problem is aggravated by the poor tillage system (Temesgen et al., 2008). Tillage is practiced traditionally through cross plowing using an ard plow (Maresha) because the implement does not permit contour plowing (Temesgen et al., 2008). Cross plowing through maresha increases surface runoff as a result of plowing up and down the slope. It has been suggested that introducing conservation tillage would alleviate the problem (Temesgen et al., 2012).

Erosion models can be used as predictive tools for soil loss assessment, conservation planning, soil erosion inventories and project planning. Moreover, the models can be used as tools for understanding erosion processes and their impact (Nearing et al., 1994). These models are basically categorized into three types namely; empirical, conceptual and physical based models (Nearing et al., 1994; Morgan, 1995; Merritt et al., 2003). Empirical models are usually statistical in nature and generally applicable only to those conditions

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for which the parameters have been calibrated (Nearing, 1994; Merritt et al., 2003).

The commonly used empirical soil erosion models include: USLE (Wischmeier and smith, 1978), RUSLE (Revised Universal Soil Loss Equation) (Renard et al., 1994), MUSLE (Modified Universal Soil Loss Equation) (Williams, 1975) and SLEMSA (Soil Loss Estimator for Southern Africa) (El well, 1978). Among these models, the USLE and MUSLE were selected. The USLE model does not estimate deposition and sediment yield as a result of ephemeral gully erosions. It is however, found to adequately represent the first order effects of the factors that affect sheet and rill erosion (Kenneth et al., 1991). As reported by many researchers, erosion modelled using the MUSLE is preferred to USLE because of its direct consideration of runoff (Kinnell and Riss, 1998; Khajehee et al., 2001; Kinnell, 2005; Seyed et al., 2007).

It is hypothesize that the application of MUSLE may be a good indicator for estimating of soil erosion by water and it will better pointer to carry out the necessity conservation planning. The purpose of this study was to estimate soil loss using USLE/MUSLE as affected by integration of conservation tillage with *fanya juus* structures in choke mountain, Ethiopia.

METHODS AND MATERIALS

Description of the Study Area

The study was carried out in East Gojjam Zone of Amhara National Regional State of Ethiopia. Enerata (Figure 1) is the study site situated between 10^{o} 24.85'N and 37^{o}44.92'E and 5 km North West of Debre Markos town, Ethiopia. The altitude is the range of 2380 – 2610m above sea level with wetter climate. The mean annual total rainfall and temperature are 1300 mm and 15^{o}C, respectively. More than 75% of the annual rain falls attain during the four months from June to September. Nitosols is the dominant soil type for specific study area (GwAo, 2010).

Data Collection Method

Experimental setup

Eight experimental plots of 5m × 30m were established to measure runoff and sediment (Figure 2). Two tillage treatments were studied in Randomized Complete Block Design (RCBD) with four replications. All plots were plowed using the traditional tillage implement (maresha) during the first pass. During subsequent passes two different tillage treatments (Figure 4) were applied: conservation tillage (CT) and traditional tillage (TT). Conservation tillage was carried out using a winged sub-soiler operated along the furrows made by the previous pass of the Maresha plow while traditional tillage involved cross plowing using *Maresha* (Temesgen, 2007). Totally, there were four pass in all experimental plots.

All selected experimental fields were newly treated with *fanya juus* as part of the routine soil conservation works of the local Bureau of Agriculture. Two crop types: wheat (*triticum vulgare*) and tef (eragrostis tef) were broadcasted on the prepared farm plots. The plots were fenced on the three sides with galvanized iron sheets inserted 20 cm into the ground while the remaining 15cm height above the surface. The fences covered the three sides while *fanya juus* bordered the lower sides of each plot (30m long) and then runoff and sediments come into the lower side of collection trench.

The design of trench was carry out after making the preliminary survey including soil texture, slope length and gradient as well as the highest rainfall intensity of the last 10 years at the study area. The designed trench dimensions are presented in Figure 3a.

Runoff and Soil loss Measurements

Runoff and soil loss were collected for 38 storm events occurred from January to September 2011 through three tied trenches for validation of the models. A sediment collection trough having three isolated parts (trenches) made of galvanized iron sheet were installed so as to measure the runoff and sediment leaving the plot (Figure 3b). Twenty pipes were attached close to the top of the lower side of the first trench. One of these pipes was connected to the second trench. The second trench would thus take 5% of the volume from the first trench and pass on 10% of its volume to the third trench through one of the ten pipes attached close to the top of its lower side. The third trench thus collected and stored 0.5% of the daily direct runoff. Therefore, daily runoff volume from the three trenches was calculated using the equation:

$$V = (H_1 L_1 + 20 H_2 L_2 + 200 H_3 L_3) W \qquad (1)$$

Where V is the daily runoff volume from the plot; H and L refer to depth of water and length of trench, respectively, in the three trenches. W is the width of runoff and sediment collection trough.

However, total sediment was calculated as the sum of bed load and suspended sediment. Bed load was carried out by depth measurements at four corners of the trench and one at the center. In addition, water sample was collected for determination of suspended sediment and analyzed using the filtration technique.

Estimation of soil erosion

For this study, USLE and MUSLE were used to estimate the soil loss by sheet erosion from the experimental plots. Equation 2 indicates that five factors namely rainfall erosivity, soil erodibility, topographic, land use and crop management (Hudson, 1982; Renard et al., 1994; Wisc-

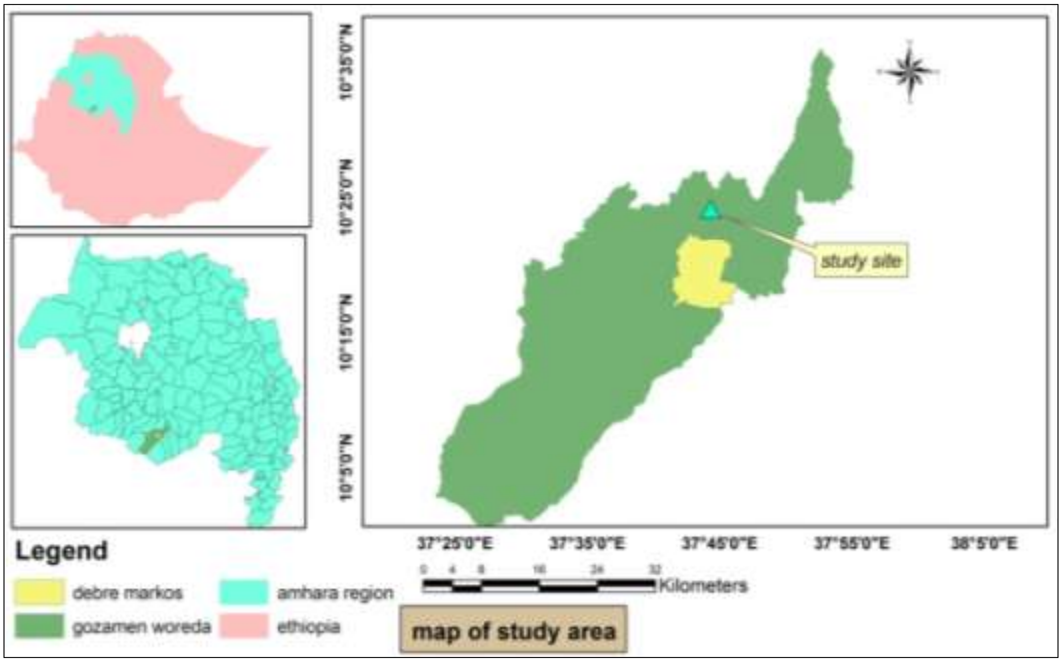

Figure 1. Map of Gozamen Woreda and location of the study area.

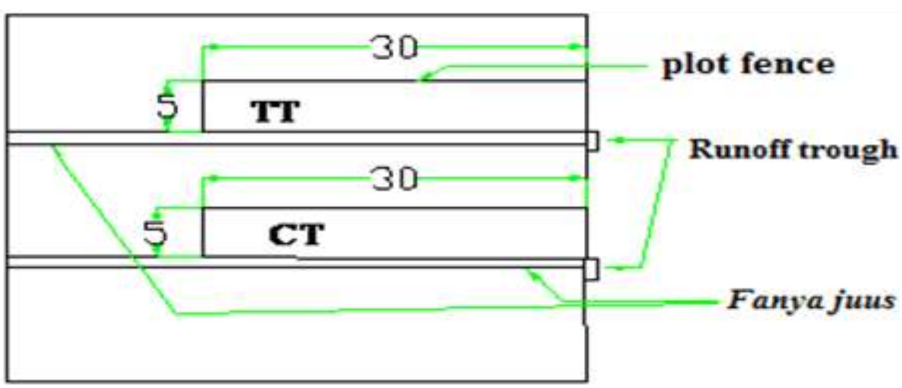

Figure 2. Layout of a single replication (in one farmer's field) farm plot.

hmeier and Smith, 1978) are necessary to predict long term average annual soil loss using the USLE soil erosion model. The equation is expressed as follows:

$$A = RKLSCP \quad (2)$$

Where *A* is the mean annual soil loss rate (t/ha/yr); *R (*rainfall erosivity), *K* (soil erodibility) *L* (slope length), *S* (slope gradient), *C* (cover and cropping management) and *P* (supporting practices) factors

Hurni (1985) has used the USLE model to assess soil erosion in Ethiopian condition and further modified the RCP factors in the model, while the KLS factors were computed based on Wischmeier (1971). These were used considered in the present study.

In addition, MUSLE was also tested based on Williams (1975) expressed as:

$$SY = 11.8(Q \times q_p)^{0.56} KLSCP \quad (3)$$

Where; SY = Sediment Yield from an individual storm in tons, Q = the storm runoff volume in m^3, q_p = the peak runoff rate in m^3 / sec.

K = soil erodibility factor, L = slope length factor, S = slope factor, C = cover and cropping management factor, P = supporting practices factor.

Model efficiency evaluation

The intended models were evaluated for the calibration

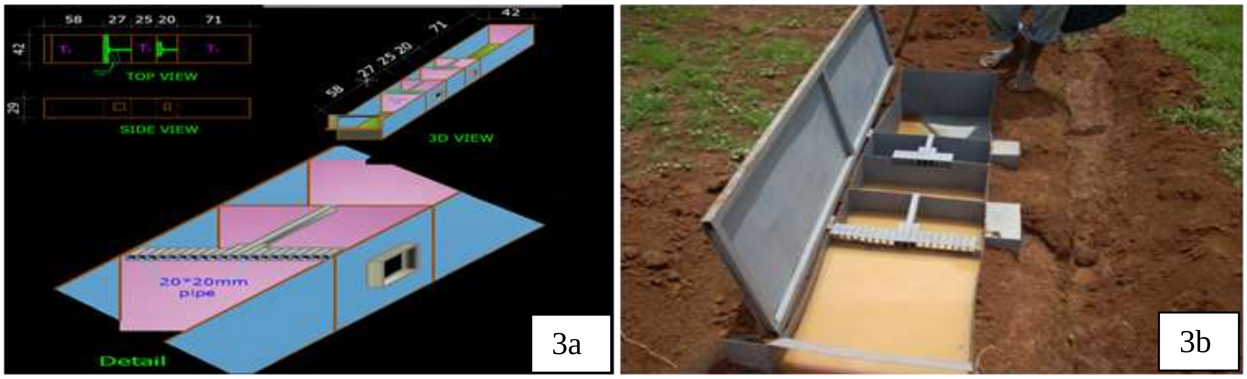

Figure 3. Design (3a) and actual (3b) runoff and sediment collection trench.

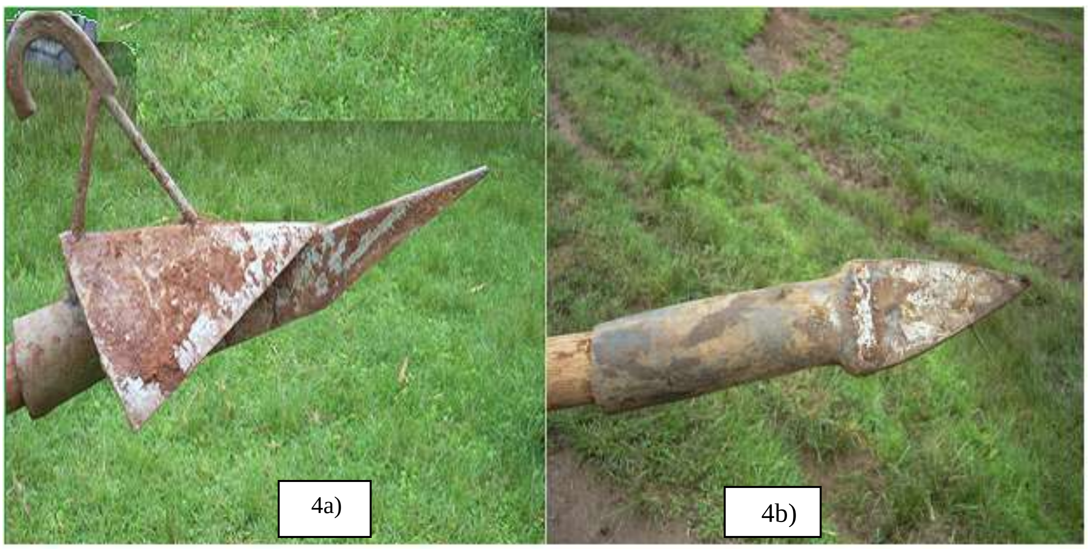

Figure 4. Winged sub-soiler (4a) and traditional (4b) ploughing implements.

and validation time periods based on Nash and Sutcliffe (1971) efficiency index (E) which is expressed as:

$$E = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O}_i)^2} \qquad (4)$$

Where P_i is the predicted soil loss for the study period, O_i is the observed soil loss value, $\overline{\overline{O}}$ the average measured soil loss and n is the total number of values within the study period. The value of ***E*** ranges from -∞ to 1, where 1 indicates the perfect fit between predicted and observed values, while 0 implies the model efficiency in predicting soil loss is equal to the mean of the observed data, but if ***E*** is less than zero the observed mean is better than the model in predicting.

RESULTS AND DISCUSSION

Calibration and Validation

Soil loss predicted by the model at the calibration and validation periods was lower than the observed on both farm plots (Table 1 and 2). This indicates that the USLE model was meant for long term average annual soil loss from sheet and rill erosion (Wischmeier and smith, 1978). As shown in Table 1 and 2, soil loss estimated by MUSLE was closer to the observed soil loss than that values estimated by USLE. A direct consideration of runoff was evident for a preferable soil loss prediction via MUSLE (Kinnell, 2005; Seyed et al., 2007).

As presented in Table 1 and 2, the highest soil loss was simulated in traditional tillage (TT) treatment on both farm plots. Since the soil bulk density (Table 6) was higher in the traditional ploughed plots, water infiltration into the soil was found to be low, which has

Table 1. Simulated soil loss values using USLE and MUSLE models at the calibration time setup.

Crop type	Treatments	$11.8(Q^* q_p)^{0.56}$	R factor	K factor	L factor	S factor	C factor	P factor	Soil loss USLE	Soil loss MUSLE
Wheat	TT	158.8	131.8	0.234	1.25	0.47	0.15	1.0	2.72	3.27
	CT	141.3	131.8	0.234	1.25	0.47	0.15	0.9	2.45	2.62
Tef	TT	173.2	131.8	0.234	1.25	0.47	0.25	1.0	4.53	5.95
	CT	158.4	131.8	0.234	1.25	0.47	0.25	0.9	4.08	4.86

Q= runoff volume, q_p peak runoff rate, R = rainfall-runoff erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope factor, C = cover and cropping management factor, P = supporting practices factor.

Table 2. Simulated soil loss values using USLE and MUSLE models at the validation time setup.

Crop type	Treatments	$11.8(Q^* q_p)^{0.56}$	R factor	K factor	L factor	S factor	C factor	P factor	Soil loss USLE	Soil loss MUSLE
Wheat	TT	131.3	110.8	0.234	1.25	0.47	0.15	1.0	2.28	2.71
	CT	103.8	110.8	0.234	1.25	0.47	0.15	0.9	2.06	1.93
Tef	TT	149.6	110.8	0.234	1.25	0.47	0.25	1.0	3.81	5.14
	CT	138.9	110.8	0.234	1.25	0.47	0.25	0.9	3.43	4.30

Table 3. Data used during modelling and model efficiency for calibration and validation time periods.

Crop type	Treatments	Data used	Reason	Simulated soil loss (t/ha) USLE	Simulated soil loss (t/ha) MUSLE	Observed soil loss (t/ha)	Nash Coeff. (E) USLE	Nash Coeff. (E) MUSLE
Wheat	TT	23/08/10-07/09/10	Calibration	2.72	3.27	4.82	0.51	0.72
		08/09/10-23/09/10	Validation	2.28	2.71	3.21	0.62	0.79
	CT	23/08/10-07/09/10	Calibration	2.38	2.62	2.94	0.68	0.85
		08/09/10-23/09/10	Validation	2.06	1.93	1.56	0.10	0.18
Tef	TT	23/08/10-07/09/10	Calibration	4.53	5.95	8.73	0.48	0.61
		08/09/10-23/09/10	Validation	3.81	5.14	5.95	0.53	0.77
	CT	23/08/10-07/09/10	Calibration	3.43	4.86	4.98	0.65	0.96
		08/09/10-23/09/10	Validation	4.08	4.30	4.77	0.71	0.84

favoured the maximum runoff production and that leads to higher soil loss. Nash coefficient (E) between observed and predicted soil loss on both farm plots at the validation time setup was found to be good as shown

Table 4. The overall response of soil loss estimated by USLE and MUSLE to changes in all input variables with ±20% at the calibration time setup.

									Simulated soil loss			
									USLE		MUSLE	
Crop type	Treatments	$11.8(Q^* q_p)^{0.56}$	R factor	K factor	L factor	S factor	C factor	P factor	SL	Base SL	SL	Base SL
Wheat	TT	127.04	105.44	0.19	1.00	0.38	0.12	0.80	0.73	2.72	0.88	3.27
	CT	113.04	105.44	0.19	1.00	0.38	0.12	0.72	0.66	2.45	0.71	2.62
Tef	TT	138.56	105.44	0.19	1.00	0.38	0.20	0.80	1.22	4.53	1.60	5.95
	CT	126.72	105.44	0.19	1.00	0.38	0.20	0.72	1.10	4.08	1.32	4.86

SL- Soil loss

Table 5. The overall response of soil loss estimated by USLE and MUSLE to changes in all input variables with ±20% at the validation time setup.

									Simulated soil loss			
									USLE		MUSLE	
Crop type	Treatments	$11.8(Q^* q_p)^{0.56}$	R factor	K factor	L factor	S factor	C factor	P factor	SL	Base SL	SL	Base SL
Wheat	TT	105.04	88.64	0.19	1.00	0.38	0.12	0.80	0.61	2.28	0.73	2.71
	CT	83.04	88.64	0.19	1.00	0.38	0.12	0.72	0.52	2.06	0.57	1.93
Tef	TT	119.68	88.64	0.19	1.00	0.38	0.20	0.80	1.02	3.81	1.38	5.14
	CT	111.12	88.64	0.19	1.00	0.38	0.20	0.72	0.92	3.43	1.16	4.30

in Table 3. This result inline with Donigian et al., (2003) who reported that expected soil loss via USLE model ranging from 2.2-15.7 and 1.1- 9.0 t/ha depending on the crop type from traditional and conservation tillage, respectively.

This result agrees with who reported that soil loss estimation through USLE/MUSLE soil loss models was lower than observed soil loss (Bobe, 2004; Seyed et al., 2007; Petru, 2010).

Sensitivity Analysis

Sensitivity analysis of soil loss simulated by USLE and MUSLE through changes in some of the factors by ±20% was tasted at the calibration and validation time setup. Changes in input variables like rainfall erosivity (R), runoff (Q) and peak runoff rate (q_p), slope length (L), slope gradient (S) and land management (P) decreased by 20% while land surface cover (C) increased by 20%. However, soil erodibility (factor K) was not considered in sensitivity analysis because of the complication resulting from several factors affecting it.

The response of soil loss estimated by USLE and MUSLE in changes of all input variables at a time with 20% decreasing or increasing (only for C factor) were tested and compared to the original simulated soil loss (Table 4 and 5). On average, soil loss using USLE and MUSLE were decreased by 26.92% and 27.01%, respectively compared to their base line simulated soil loss value (Table 4 and 5). The overall result showed that simulated soil loss decreased as percentage of changes in input variables increased or decreased. In line with this, the effects of these input variables are good indicators in soil loss reductions and also to take an action regarding on soil management options.

CONCLUSION

Validation of the USLE/ MUSLE models for plot-sized area was examined at the Choke Mountain of Ethiopia.

Table 6. Summary of ANOVA results for bulk density (g cm^{-3}), organic matter and particle size distribution (%) in relation to tillage system and soil depth.

Variables	Depth (cm)	Tillage system Traditional	Conservation
Bulk density	0-10	0.98±0.005	0.93±0.005
B_d	10-20	1.11±0.006	1.03±0.005
(g cm^{-3})	20-30	1.13±0.005	1.12±0.003
	Overall	1.07±0.005^a	1.03±0.043^b
OM (%)	0-10	2.49±0.005	2.51±0.004
	10-20	2.11±0.005	2.11±0.006
	20-30	1.76±0.009	1.77±0.007
	Overall	2.12±0.006^a	2.13±0.005^a
Sand	0-10	45.74±0.47	45.76±0.48
	10-20	50.17 ±0.93	50.0±0.91
	20-30	48.16 ±0.41	48.2±0.39
	Overall	48.02 ±0.6^a	48.02±0.59^a
Silt	0-10	32.16±0.70	32.10±0.71
	10-20	24.32±0.41	24.26±0.39
	20-30	16.11±0.43	16.18±0.41
	Overall	24.20±0.51^a	24.18±0.50^a
Clay	0-10	22.05±0.88	22.01±0.91
	10-20	25.73±0.85	25.75±0.81
	20-30	36.50±0.29	36.54±0.28
	Overall	28.09±0.67^a	28.10±0.66^a

Mean±SE followed by the same letter across the row are not significant (p=0.05) with respect to soil depths.

The MUSLE application was better to estimate soil loss than the USLE at cultivated fields. This was due to runoff which was considered as an input for MUSLE model, and was a better indicator than rainfall for sediment prediction. Based on the study, tillage system (P factor) had greater influence on soil loss. Further research is needed on establishment of long-term records of rainfall-runoff-sediment data for a better sediment yield modelling. Then, such model would lead to better soil and water conservation and watershed management plannings.

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REFERENCES

Bobe BW (2004). Evaluation of soil erosion in the Harerge region of Ethiopia using soil loss models, rainfall simulation and field trials. PhD Thesis. University of Pretoria. Pretoria.

Donigian AS, Love JT (2003). Sediment Calibration Procedures and Guidelines for Watershed Modelling. WEF TMDL. Chicago, Illinois.

El Well HA (1978). Modelling soil losses in southern Africa. J. Agric. Eng. Res. (23): 117-127.

FAO (1986). Ethiopian highlands reclamation study. Final report. FAO, Italy.

GwAo (Gozamen Woreda Agricultural Office) (2010). Annual Report for the Year 2010/2011 (In Amharic). (Unpublished Report). Gozamen Woreda Office of Agriculture, Debre-Markos, Ethiopia.

Hudson N (1982). Soil conservation. B.T. Batsford Ltd. London. 275–281.

Hurni H (1985). Erosion - productivity – conservation systems in Ethiopia. In: proceedings of the fourth International Conference on soil conservation, Maracay, Venezuela.

Hurni H (1993). Land Degradation, Famines and Resource Scenarios in Ethiopia. In: Pimentel, D. World soil erosion and conservation. Cambridge University Press. Cambridge. 27– 62.

Kenneth GR, George RF, Glenn AW, Jeffrey PP (1991). RUSLE: Revised Universal Soil Loss Equation. J. Soil Water Conserv. 42.

Khajehee A, Broshkeh A, Sokouti R, Arabkhedri M (2001).

Study on application of empirical model of MUSLE in Shahrchai watershed. Proceedings National Seminar on Land Management, Soil Erosion and Sustainable Development, Arak, Iran. 436-446.

Kinnell PIA (2005). Why the universal soil loss equation and the revised version of it do not predict event erosion well? Hydrological Processes (19): 851-854.

Kinnell PIA, Riss LM (1998). USLE-M: Empirical modeling rainfall erosion through runoff and sediment concentration. J. Am. Soil Soc. (62): 1662-1672.

Merritt WS, Letcher RA, Jakeman AJ (2003). A review of erosion and sediment transport models. Environmental modelling and Software, (18): 761-799.

Morgan RP (1995). Soil Erosion and Conservation, second ed. Longman Group Ltd., Harlow. 152.

Nash JE, Sutcliffe JV (1971). River flow forecasting through conceptual models. J. Hydrol. (13): 297-324.

Nearing MA, Lane LJ, Lopes VL (1994). Modelling Soil Erosion. In: Lal, R. (Ed.), soil erosion research methods, 2nd edition.

Petru C (2010). The dimensional analysis of the USLE-MUSLE soil erosion model. National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry (INMA). Bucharest, Romania.

Renard KG, Laflen JM, Foster GR, McCool DK (1994). The Revised Universal Soil Loss Equation. In: Lal R. (Ed.), Soil Erosion Research Methods (2nd edition) USDA.

SCRP (1985). Soil loss and runoff assessment findings, Soil Conservations Researches Project (SCRP). Addis Ababa, Ethiopia.

Sutcliffe JP (1993). Economic assessment of land degradation in the Ethiopian Highlands. A Case Study. National Conservation Strategy Secretariat, Ministry of Planning and Economic Development. Addis Ababa, Ethiopia: Transitional Government of Ethiopia. 84–97.

Seyed HS, Takahisa M, Babak GV (2007). Conformity of MUSLE Estimates and Erosion Plot Data for Storm-Wise Sediment Yield Estimation. Terrestrial, atmospheric and oceanic sciences, (18): 117-128.

Tamene L (2005). Reservoir siltation in the dry lands of northern Ethiopia: causes, source areas and management options. PhD Thesis, Ecology and Development Series 30, Center for Development Research, University of Bonn.

Temesgen M, Uhlenbrook S, Simane B, van der Zaag P, Mohamed Y, Wenninger J, Savenije HHG (2012). Impacts of conservation tillage on the hydrological and agronomic performance of fanya juus in the upper Blue Nile (Abbay) river basin. Hydrology and Earth System Sciences Discussions.

Temesgen M, Rockstrom J, Savenije HHG, Hoogmoed WB, Alemu D (2008). Determinants of tillage frequency among smallholder farmers in two semi-arid areas in Ethiopia. University Press, Cambridge. Physics and Chemistry of the Earth, (33): 183–191.

Temesgen M (2007). Conservation Tillage Systems and Water Productivity Implications for Smallholder Farmers in Semi-arid Ethiopia. PhD Thesis. Taylor & Francis/Balkema, Leiden, the Netherlands. 9-16

Williams JR (1975). Sediment-yield prediction with universal equation using runoff energy factor. In Present and Prospective Technology for Predicting Sediment Yields and Sources, (Proceedings of the Sediment-Yield Workshop, USDA Sedimentation Laboratory, Oxford, Mississippi, November 28-30). 244-252.

Wischmeier WH, Smith DD (1978). Predicting rainfall erosion losses--A guide to conservation planning: Agricultural Handbook no. 537, Sci. and Educ. Admin., U.S. Dept. Agr., Washington, D.C.

Wischmeier WH, Johnson CB, Cross BV (1971). A soil erodibility nomograph for farm land and construction sites. J. Soil Water Conserv. (28): 189-193.