University of Natural Resources and Life Sciences, Vienna

Department of Water, Atmosphere and Environment

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Doctoral Thesis

Soil erosion assessment and crop management as strategies for watershed management improvement

To obtain the academic degree of Dr. nat. techn.

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Submitted by:

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Austria, Vienna

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Declaration

I, hereby declare to the University of Natural Resources and Applied life Sciences, Vienna that this is my original thesis work and all sources of materials used are duly acknowledged. This work has not been submitted to any other educational institutions for achieving any academic degree awards.

Name: **Nigus Demelash Melaku**

Signature:

Place and time: Vienna, January 2018

Dedication

This research is dedicated for those who lost their life for freedom, justice and equality in Ethiopia

Acknowledgement

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I would like to express my sincere gratitude to all the team of researchers and scientists that contributed to the success of this research. I would like to express my deepest gratitude to my major supervisor Prof. Andreas Klik for his unreserved help in supervision, guidance, intellectual encouragement, patience and critical and constructive comments during the 3 years of study. Without his help and support, this thesis could never have been completed. I would also like to express my sincere gratitude for the guidance and patience provided by my advisor Prof. Chris Renschler. He is a model advisor and taught me many things and has offered me a great deal of constructive feedback, as well as valuable and very critical comments on the research outputs while I was at his Laboratory at the University at Buffalo, New York. I also want to thank my Co-supervisors Prof. Hubert Holzmann, Dr. Wondimu Bayu, Dr. Stefan Strohmeier, Dr Claudio Zucca and Dr Feras Ziadat for their constant support. I have very special gratitude for all staff members of my home institute (GARC and ARARI) for their incredible support all the time.

As this work took place in the greater context of a project there were many cooperation partners that gave us great technical and financial support during the entire study. Here, I want to mention BOKU, ICARDA, ARARI, GARC, Gondar Soil Lab, Marshal Plan and University at Buffalo (LESAM) as well as the ADA. A special expression of gratitude goes to the farmers in the Gumara-maksegnit watershed who provided me with good insight on how to work with the community and for protecting the instruments installed in the watershed. I have a special respect and appreciation for them. I express my greatest gratitude to my parents that always gave me all encouragement and freedom I needed to reach my goals and always believed in what I was doing. Last but not least, I want to thank my friends that support but also challenge me day by day and make life interesting.

I acknowledge the anonymous reviewers for taking their time and effort necessary to provide such insightful guidance and very important comments.

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Abstract

Land degradation and low agricultural productivity are severe problems in the highlands of Ethiopia. Various soil and water conservation (SWC) strategies have been in use to tackle soil erosion. However, the effectiveness of SWC measures on runoff dynamics and sediment load in terms of their medium- and short-term effects has not been sufficiently studied. A study was conducted in 2011 through to 2015 in the Gumara-Maksegnit watershed to study the impacts of SWC structures on runoff and soil erosion processes using SWAT model. The study was conducted in two adjacent watersheds where in one of the watersheds SWC structures were constructed (Treated watershed-TW) in 2011, while the other watershed was a reference watershed without SWC structures (Untreated watershed-UW). Runoff and sediment yield were compared based on the observations and model simulations. The result of runoff simulation indicated that SWAT can simulate the hydrological regime for both watersheds. The daily runoff calibration result for the TW and UW showed good correlation between the predicted and the observed data (R^2 = 0.78 for the TW and R^2=0.77 for the UW).The validation result also showed good correlation with R^2 values of 0.72 and 0.70 for the TW and UW, respectively. Sediment yield calibration and validation results showed modest correlation between the predicted and observed sediment yields with R^2 values of 0.65 and 0.69 for the TW and UW for the calibration and R^2 values of 0.55 and 0.65 for the TW and UW for the validation, respectively. The model results indicated that SWC structures considerably reduced soil loss by as much as 25-38% in the TW. The study proved that SWAT performed well for both watersheds and can be a potential instrument for out and up-scaling to assess and design SWC structures impact in the highlands of Ethiopia. The results confirmed that SWC structures have a significant impact to prevent land degradation in the Ethiopian highlands.

Keywords: soil erosion**,** Runoff; Sediment yield; SWAT; soil and water conservation; Ethiopia

Abstrakt

Bodendegradation und geringe landwirtschaftliche Produktivität sind schwerwiegende Probleme im Hochland von Äthiopien. Verschiedene Boden- und Wasserschutzstrategien wurden zur Bekämpfung der Bodenerosion entwickelt und eingesetzt. Die Wirksamkeit dieser Maßnahmen auf Abflussdynamik und Sedimentbelastung in Bezug auf ihre mittel- und kurzfristigen Auswirkungen wurde jedoch nicht ausreichend untersucht. Von 2011 bis 2015 wurde im Einzugsgebiet von Gumara-Maksegnit in Äthiopien eine Studie durchgeführt, um die Auswirkungenvon Bodenschutzmaßnahmen auf Abfluss und Bodenerosionsprozesse mithilfe von SWAT Modellen zu untersuchen. Die Studie wurde in zwei angrenzenden Einzugsgebieten durchgeführt, wovon eines mit Bodenschutzmaßnahmen versehen war (Treated Watershed-TW), während das andere ohne Schutzmaßnahmen war (Unbehandeltes Waterhed-UW). Abfluss und Sedimentaustrag wurden basierend auf den Beobachtungen simuliert und miteinander verglichen. Das Ergebnis der Abflussberechnung zeigte, dass SWAT das hydrologische Regime für beide Wassereinzugsgebiete simulieren kann. Das tägliche Abflusskalibrierungsergebnis für TW und UW zeigte eine gute Korrelation zwischen den vorhergesagten und den beobachteten Daten (R^2=0,78 für die TW und R^2=0,77 für die UW). Das Validierungsergebnis zeigte auch eine gute Korrelation mit R^2-Werten von 0,72 und 0,70. für die TW bzw. UW. Kalibrierung und Validierung für Sedimentaustrag zeigten eine mäßige Korrelation zwischen den vorhergesagten und den beobachteten Erosionsraten mit R^2 Werten von 0,65 und 0,69 für die TW und UW für die Kalibrierung und R^2Werten von 0,55 und 0,65 für die Validierung. Die Modellergebnisse zeigten, dass Strukturen wie etwa stone bunds den Bodenverlust um bis zu 25-38% reduzieren. Die Studie hat bewiesen, dass SWAT für beide Wassereinzugsgebiete ausreichend genaue Ergebnisse liefert und somit ein und ein Instrument für Outscaling sein können, um die Auswirkungen der Bodenschutzmaßnahmen im Hochland von Äthiopien bewerten und gestalten zu können. Die Ergebnisse bestätigten überdies, dass die untersuchten Bodenschutzmaßnahmen einen signifikanten positiven Einfluss auf eine nachhaltige Bodenbewirtschaftung im äthiopischen Hochland haben.

Stichwörter: Bodenerosion, Abfluss; Sedimenteintreg; SWAT;
Bodenschutzmaßnahmen; Äthiopien

Table of Content

1. Introduction

Soil erosion by water is a worldwide phenomenon leading to loss of nutrient-rich surface soil, increased runoff from the more impermeable subsoil and decreased water availability to plants (Ganasri and Ramesh, 2015). Soil erosion and loss of soil fertility are among the challenges to the economic development of Ethiopia which results in poverty, food insecurity and natural resources degradation. Average crop yield is low due to soil fertility decline associated with the removal of top soil by erosion (Sertsu, 2000).Constable and Belshaw (1986) estimated that 50% of the Ethiopian highlands were already significantly eroded in the mid 1980s. This resulted in a 2.2% annual decline in land productivity and projected a reduction in per-capita income of the highland population by 30% (Tamene and Vlek, 2008).

With limited resources and poor access to inputs, management of soil fertility is essential to strengthen and sustain ecosystem services. Soil degradation is a 21st century global problem that is especially severe in the tropics and sub-tropics. Some estimates indicate degradation decreased soil ecosystem services by 60% between 1950 and 2010 (Leon and Osorio, 2014). Accelerated soil degradation has reportedly affected as much as 500 million hectare (Mha) in the tropics (Lamb et al., 2005), and globally 33% of earth's land surface is affected by some type of soil degradation (Bini, 2009). In addition to negatively impacting agronomic production, soil degradation can also dampen economic growth, especially in countries where agriculture is the engine for economic development (Scherr, 2001). In order to reduce this soil degradation problem, Soil erosion must be done to the tolerable limits and soil fertility management should be improved.

In the Ethiopian highlands deforestation for crop production, cultivation of marginal lands and overgrazing dramatically increased the vulnerability of agricultural lands to rainfall driven soil erosion (Nyssen *et al.*, 2000; Vancampenhout *et al.*, 2006; Addis *et al.*, 2016). Intensive rainfall during the rainy season (June to September) threaten the mountainous regions to severe land degradation especially on the steep sloped and unprotected areas (Addis *et al.*, 2016).To tackle the soil erosion problem in the Ethiopian highlands constructing soil and water conservation structures is considered to be a top priority in reducing land degradation and thus to improve agricultural productivity.

Since 2010 a massive effort has been undertaken by the government of Ethiopia in constructing soil and water conservation structures on private owned and community lands through community mobilization (Kebede 2014; Dagnew et al. 2015; Teshome et al. 2016; Dagnew et al. 2017; Girum et al. 2017; Guzman et al. 2017;). Examples of soil and water conservation practices include stone bunds, soil bunds, percolation ditches (Teshome et al., 2016). However, the effectiveness of these soil and water conservation measures on the dynamics of runoff and sediment loading has not been sufficiently studied and identified clearly for long and short-term effects in the Ethiopian highlands.

In this dissertation, prediction of the impact of soil and water conservation structures on runoff and soil loss in the highlands of Ethiopia is presented in chapter 5. The runoff and sediment loss are quantified by measurements and simulation using SWAT model in two paired watersheds in the Highlands of Ethiopia. The investigation was done in paired watershed where one of the watersheds is treated with SWC and the other one is used as a reference watershed without SWC as presented in chapter 5. This dissertation also presents effects of the rate and timing of nitrogen fertilizer application on the possibility of decreasing the maturity period while increasing the productivity of sorghum on the Vertisols of the Gumara-Maksegnit watershed (Chapter 6).

2. Hypotheses and objectives

This thesis follows the motivation to contribute research results to the scientific community with the objective of assessing the effectiveness of soil and water conservation structures on soil loss and improving sorghum productivity in vertisol management. The following main hypotheses were assumed:

• Soil and water conservation structures could reduce runoff and soil erosion.

•Fertilizer management in vertisols could improve crop productivity and shorten the growth period.

The hypotheses resulted in the following main research objectives:

• Assessing the impact of stone bunds on runoff and sediment yield

• Assess the effects of the rate and timing of nitrogen fertilizer application on the possibility of decreasing the maturity period and increasing the productivity of sorghum on the Vertisols.

3. Structure of the study

This doctoral thesis consists of two independent chapters. In chapter 5, the impact of soil and water conservation structures on runoff and erosion processes are presented using SWAT in the Northern Ethiopian highlands. A field study was conducted in two adjacent watersheds where in one of the watersheds SWC structures were constructed (Treated watershed-TW) while the other watershed was a reference watershed without SWC structures (Untreated watershed-UW). Field measurements and model simulations were carried out for the two study watershed. The field measurements and the model simulation results were then used for the analysis of the effectiveness of soil and water conservation structures. In addition the effect of different levels of nitrogen fertilizer and its split application on yield and yield related parameters of sorghum were assessed in Gumara-Maksegnit watershed in Chapter 6. Field measurements and observations were done. The collected field measurement data were analyzed to determine the optimum fertilizer rate and application.

4. Dissemination

Since this is a cumulative doctoral thesis, the central parts of the study were subject to scientific publications in peer-reviewed journals (Thomson Reuters/Science Citation Index (SCI) Web of Science List). Therefore, the international communities can have access to share our experience and applied the procedures in future studies of similar regions. Details are listed in Tables 4.1 and 4.2.

Table 4.1 List of scientific publications in journals that are under Thomson Reuters/SCI Web of Science List

Chapter	SCI-Journal	Impact factor	Title
5	Journal of Soils and Sediments	2.522	Prediction of soil and water conservation structure impacts on runoff and erosion processes using SWAT model in the Northern Ethiopian highlands.
6	Archives of Agronomy and Soil Science	2.137	Effect of nitrogen fertilizer rate and timing on sorghum productivity in Ethiopian highland Vertisols
7	CATENA	3.191	Assessing the impact of soil and water conservation structures on runoff and erosion processes through measurements and modeling .(Under revision)

Table 4.2 List of presentation on international scientific conference

Chapter	Conference	Date and City	Title and type of presentation
	EGU General Assembly 2017,	April 8–13, 2017, Vienna, Austria	Comparison of SWAT and GeoWEPP model in predicting the impact of stone bunds on runoff and erosion processes in the Northern Ethiopian Highlands. EGU General Assembly 2017. Geophysical Research Abstracts. Vol. 19, EGU2017-6970-1, 2017.
	10th International Symposium on Agriculture and the Environment	May 23-27, 2016, Indiana; USA	Improving Sorghum Productivity in Waterlogged Vertisols in North Gondar, Ethiopia. AgroEnviron 2016, Purdue University, West Lafayette, IN; 06/2016.
	10th International Symposium on Agriculture and the Environment	May 23-27, 2016, Indiana; USA	Impact of cover crop on runoff, soil loss, soil chemical properties and yield of chickpea in North Gondar, Ethiopia. AgroEnviron 2016, Purdue University, Wets Lafayette, IN; 08/2016.
	10th International Symposium on Agriculture and the Environment	May 23-27, 2016, Indiana; USA	Impacts of Stone Bunds on Soil Loss and Surface Runoff: A Case Study from Gumara Maksegnit Watershed, Northern Ethiopia. AgroEnviron 2016, Purdue University, Wets Lafayette, IN; 06/2016.
	EGU General Assembly 2016,	23–28 April 2016, Vienna, Austria.	Impact of cover crop on runoff, soil loss, soil chemical properties and yield of chickpea in North Gondar, Ethiopia. EGU General Assembly2016; Vol.18, EGU2016-2464, 2016.

[1]Melaku ND, Bayu W, Strohmeier S, Ziadat F, Zucca C, Klik A. 2017. Archives of Agronomy and Soil Science

[1]Melaku ND, Renschler CH, Strohmeier S, Holzmann, Ziadat F, Zucca C, Bayu W, Klik A. 2017. Journals of Soils and Sediments

[1]Melaku ND, Renschler CH, Flagler J, Bayu W, Klik A. 2017. CATENA

5. Prediction of soil and water conservation structure impacts on runoff and erosion processes using SWAT model in the Northern Ethiopian highlands

Abstract

Land degradation due to soil erosion is a serious threat to the highlands of Ethiopia. Various soil and water conservation (SWC) strategies have been in use to tackle soil erosion. However, the effectiveness of SWC measures on runoff dynamics and sediment load in terms of their medium- and short-term effects has not been sufficiently studied. A study was conducted in 2011 through to 2015 in the Gumara-Maksegnit watershed to study the impacts of SWC structures on runoff and soil erosion processes using SWAT model. The study was conducted in two adjacent watersheds where in one of the watersheds SWC structures were constructed (Treated watershed-TW) in 2011, while the other watershed was a reference watershed without SWC structures (Untreated watershed-UW). For both watersheds, separate SWAT and SWAT-CUP (SWAT Calibration and Uncertainty Procedure) projects were setup for daily runoff and sediment yield. SWAT-CUP program was applied to optimize the parameters of the SWAT using daily observed runoff and sediment yield data. The result of runoff simulation indicated that SWAT can simulate the hydrological regime for both watersheds. The daily runoff calibration (2011-2013) result for the TW and UW showed good correlation between the predicted and the observed data (R^2 = 0.78 for the TW and R^2 = 0.77 for the UW). The validation (2014-2015) result also showed good correlation with R^2 values of 0.72 and 0.70 for the TW and UW, respectively. However, sediment yield calibration and validation results showed modest correlation between the predicted and observed sediment yields with R^2 values of 0.65 and 0.69 for the TW and UW for the calibration and R^2 values of 0.55 and 0.65 for the TW and UW for the validation, respectively. The model result indicated that SWC structures considerably reduced soil loss by as much as 25-38% in the TW. The study proved that SWAT performed well for both watersheds and can be a potential instrument for out and up-scaling to assess and design SWC structures impact in the highlands of Ethiopia.

Keywords Runoff • Sediment yield • SWAT • SWAT-CUP • SWC• Watershed

5.1. Introduction

Degradation of agricultural land as a result of soil erosion is a worldwide phenomenon leading to loss of nutrient-rich surface soil and increased runoff from the more impermeable subsoil that leads to lowering agricultural productivity (Erkossa et al. 2015; Taguas et al. 2015; Ganasri and Ramesh 2015; Keesstra et al. 2016; Nigussie et al. 2017). Soil erosion is more severe in the Sub-Saharan African countries where the population livelihood is dependent on the soil (Sunny et al. 2012; Erkossa et al. 2015). In the Ethiopian highlands deforestation for crop production, cultivation of marginal lands and overgrazing are the major factors that dramatically increased the vulnerability of agricultural lands to rainfall-driven soil erosion (Nyssen et al. 2000;Vancampenhout et al. 2006; Belay et al.2013; Adimassu et al. 2014; Erkossa et al. 2015; Addis et al. 2016). Intensive rainfall during the rainy season (June to September) threatens the mountainous regions to severe land degradation especially on the steep sloped and unprotected areas (Addis et al. 2016).To tackle the soil erosion problem in the Ethiopian highlands, constructing soil and water conservation structures is considered to be a top priority in halting land degradation and thus to improve agricultural productivity.

Since 2010 a massive effort has been undertaken by the government of Ethiopia in constructing soil and water conservation structures on private owned and community lands through community mobilization (Kebede 2014; Dagnew et al. 2015; Teshome et al. 2016; Dagnew et al. 2017; Girum et al. 2017; Guzman et al. 2017). Examples of soil and water conservation practices include stone bunds, soil bunds, percolation ditches, etc are constructed (Teshome et al. 2016). However, the effectiveness of these soil and water conservation measures on the dynamics of runoff and sediment loading has not been sufficiently studied and identified clearly for long and short-term effects in the Ethiopian highlands.

In the Northern highlands of Ethiopia, different studies have been carried out on the impacts of soil and water conservation structures on erosion process at field scale (Kaltenleithneret al. 2014; Rieder et al. 2014; Strohmeier et al. 2015; Klik et al. 2016; Obereder et al. 2016). These studies reported that the SWC structures are effective at plot scale in the Gumara-maksegnit watersheds. However, studies on the impacts of soil and water structures on erosion process at watershed scale are limited. As data from field experiments cannot be extrapolated to a watershed scale

(Verstraeten et al. 2006), the use of mathematical models for evaluating soil and water conservation measures is quite common.

Insufficient information on soil erosion and streamflow could lead to inefficient planning and inadequate design and operation of soil and water resource management projects (Poitras et al. 2011). Changes in the extent of seasonal precipitation, frequency and intensity of extreme precipitation events directly affect the amount of seasonal streamflow (Poitras et al. 2011). The prediction and assessment of streamflow and sediment yield using a watershed model are important for agricultural watershed management in the Ethiopian highlands as watershed models are crucial tools to illustrate hydrological processes and to scale up the model results.

SWAT (Soil and Water Assessment Tool) (Arnold et al.1998) is a continuous-time, semi-distributed, process-based river basin or watershed scale model. The model is one of the most comprehensive models able to evaluate hydrologic processes (Gassman et al. 2007). SWAT has been employed to simulate the discharge in the Ethiopian highlands (Setegn 2008; Setegn et al. 2009; Easton et al. 2010; Setegn et al. 2010; Betrie et al. 2011; Setegn et al, 2011; Yasir et al. 2014). Hence, the objective of this study was 1) to calibrate and validate the SWAT model for two watersheds with and without soil and water conservation (SWC) structures, 2) to study the impact of these structures on runoff and erosion processes, and 3) to provide feedback on the efficiency of the structures in reducing soil erosion in the watersheds and to advise future up-scaling.

5.2. Materials and Methods

5.2.1. Description of the study area

The two study watersheds, TW and UW, are located in the Gumara-Maksegnit watershed in northwest Ethiopia (Figure 1). The watershed drains into the Gumara river, which finally drains into Lake Tana. The two watersheds are located at 12°25’24’’ and 12°25’54’’ latitude and at 37°34’56’’ and 37°35’38’’ longitude and at an altitude ranging from 1998 to 2150 meter above sea level (Figure 5.1). The two study watersheds are neighboring each other at a distance of about 1 km between the outlets which embrace an area of 31.7 ha for the TW and 27.1 ha for the

UW. About 80% of the area of the watersheds have >10 % slope. The soil types found in the watershed are Cambisol and Leptosol which are found in the upper and central part of the watershed, while Vertisol is found in the lower catchment. The watershed has a long term (1997-2015) annual rainfall of 1157 mm with 80% raining from June to September and a mean minimum and maximum temperatures of 13.3 °C and 28.5 °C (Addis et al., 2016).

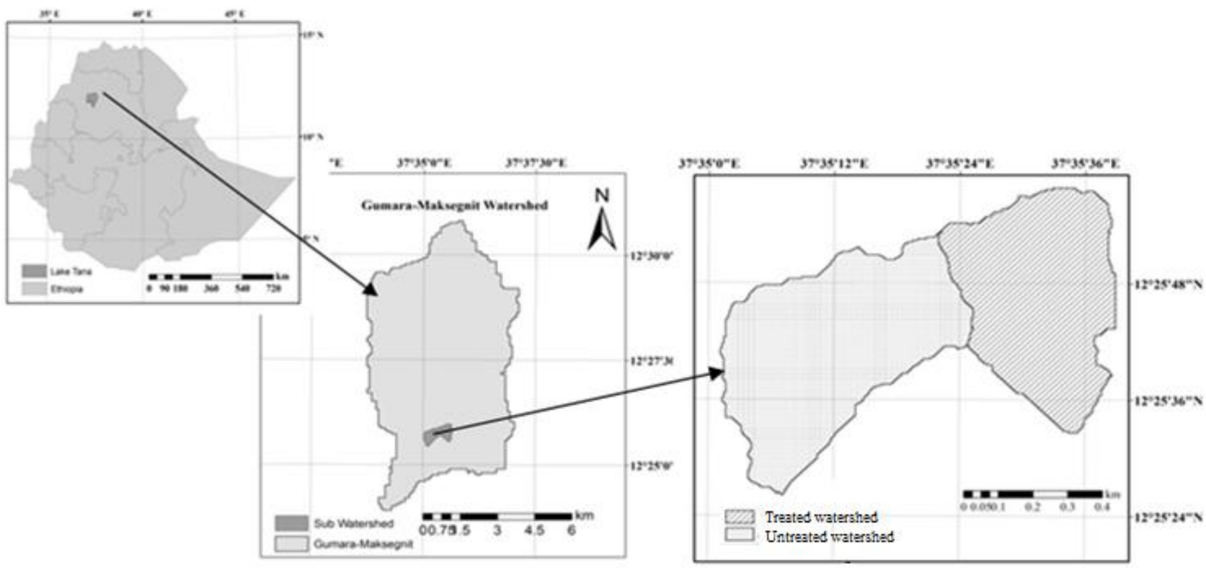

Figure 5.1 Maps of Ethiopia (left top), the larger Gumara-Maksegnit watershed (middle) and the two-paired watersheds (right)

In 2011 SWC structures mainly stone bunds were constructed in the first watershed (TW) (Figure 5.2). On farmlands 40 cm high stone bunds at distances ranging between 15 and 25 m depending on the steepness of the land were constructed. While in the gullies check dams at various intervals were constructed using gabions. The second watershed was used as a reference without SWC structures.

Figure 5.2 Erosion plot experiments (left) and SWC structures (right) at the treated watershed

5.2.2. SWAT model and model input

Arc SWAT (Arnold *et al.*, 1998) was used to estimate the runoff and sediment yield in the TW and UW watersheds. Surface runoff was modified by the adjustment of the runoff ratio (Curve Number) while SWC structures impacts on sediment yield were adjusted through the support practice factor (P-factor) and/or the slope length factor (LS).

In this study, Curve Number values were modified by editing Management (.mgt) input table from the field experiment results (Klik *et al.*, 2016) while the SLSSUBSN value was modified by editing the HRU (.hru) input table. The model divides watersheds into a number of sub-basins during watershed delineation and adopts the concept of the Hydrologic Response Unit (HRU), which represents the unique property of each parameter. SWAT is able to simulate runoff based on separate HRUs, which are aggregated to generate output from each sub-basin. Model output results like surface runoff, sediment yield, soil moisture, nutrient dynamics, crop growth etc., are simulated for each HRU, aggregated and processed to sub-basin level results on a daily time step resolution. SWAT model requires input data, which can be supplemented with GIS data and the model interface (Di Luzio *et al.*, 2002).

For this study, SWAT offers finer spatial and temporal scales, which allows observing an output at a particular sub-basin on a daily base. It considers comprehensive hydrological processes, estimating surface runoff, sediment yield, nutrients, groundwater flow and channel processes within each sub-basin and at the watershed scale. The sediment yield and runoff results from ArcSWAT model were compared with the observed daily data collected from both watersheds was used to evaluate the performance of the model. The DEM, land use, soil and climate data were used for SWAT model inputs.

Model input

A DEM was developed based on conventional terrestrial surveying using total stations to obtain the topographic characteristics of the watersheds. The DEM was used to derive topographical parameters and automatically delineate watershed boundaries and channel networks. The -watersheds were divided into five slope steepness classes, namely: 0-10%, 10-20%, 20-30%, 30-

40% and greater than 40% (Figure 5.3). The land use maps of both watersheds were evaluated based on the satellite image and ground truth data. A parcel as a polygon was developed containing a single land use using the Google earth imagery taken on 14/10/2011 and cross checking was done using the ground truth data. The study watersheds have nine land use classes (Figure 5.3). The land use percentages of each watershed are summarized in Table 5.1.

Table 5.1 Land use and land cover in the Untreated and Treated watersheds

Land use type	Untreated watershed (UW)	Treated watershed (TW)
Barley	4.7%	2.3%
Lentils	6.2%	4.6%
Green Beans	5.9%	7.4%
Pasture	2.4%	6.9%
Corn	10.1%	5.1%
Mixed forest	33.2%	30.4%
Grain sorghum	28.4%	27.3%
Eragrostis teff	4.1%	9.1%
Wheat	5.0%	6.9%
Total	100%	100%

Intensive soil sampling was carried out to determine selected soil properties in a 100 meter by 100 meter grid in the two watersheds. At each location, about two kilograms of bulk soil were taken from different soil layers (0-25cm), (25-60cm) and (60-100cm) for physical and chemical analyses. Spatial distribution of soil textures and other soil properties were determined in the field and in the laboratory. The major soil textural classes in the UW are clay (3.7%), clay loam (52.9%), loam (36.3%), silty clay loam (4.7%) and silty loam (2.9 %). In TW, the major soil types are clay (12.4%), clay loam (50.7%), loam (23.4%), silty clay loam (0.16%) and silty loam (12.9 %) (Figure 5.3).

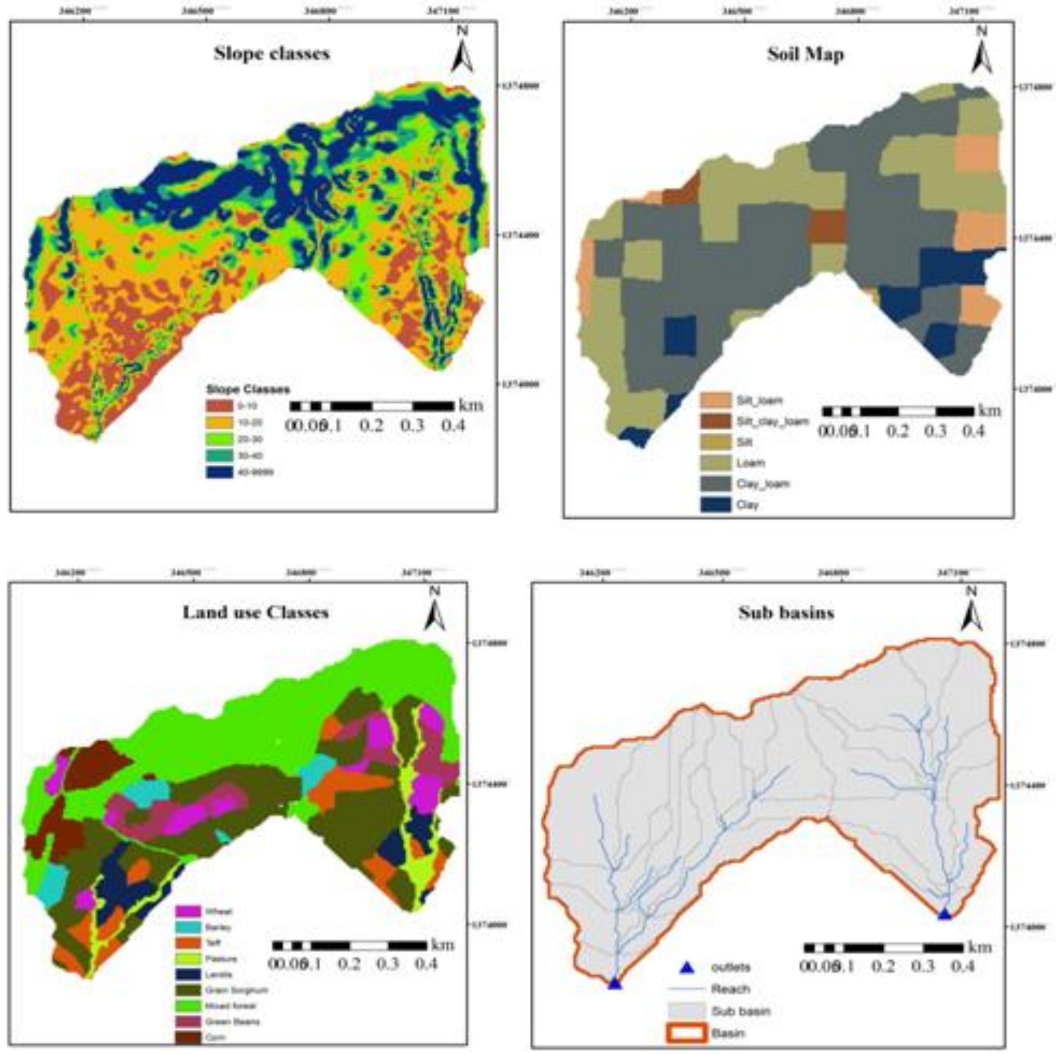

Figure 5.3 Slope classes, soil map, land use classes and sub-basins of both watersheds

The required daily precipitation and temperature data were collected from the weather station located at the UW outlet. Daily solar radiation, relative humidity, and wind speed data were recorded from an automatic metrological station located at approximately 5 km far from the watersheds. The SWAT weather generator was used for simulating missing daily weather data (Schuol and Abbaspour, 2007). Daily climatic data (January 1, 1997 to December 31, 2015) recorded at the weather stations were used to create the monthly weather statistics using the weather generator.

Runoff discharge and Sediment yield

Runoff and sediment yield were collected at the outlet of both watersheds where rectangular v-notch weirs with flow sensors and automatic cameras were installed to measure surface runoff.

The automatic cameras were set to take pictures every 2 minutes (Figure 5.4). At each rainfall event, three runoff samples distributed over the whole runoff event were collected manually where subsequently sediment concentration of each sample was determined in the laboratory. Sediment yield was then calculated multiplying discharge by the mean sediment concentration. The data were used to calibrate and verify a distributed simulation model.

Figure 5.4 Pictures taken from the automatic camera at day (left) and nighttime (right)

5.2.3. Project set up

For each watershed a separate SWAT project was setup. The modeled period was from 2004 to 2015. Runoff and sediment yield data collected from the watersheds during 2011 to 2013 were used for model calibration while data from 2014 to 2015 were used for validation. Mean daily runoff and sediment data from both watersheds were used to calibrate the SWAT model. Some of the appropriate parameters were adjusted until the predicted daily runoff (Table 5.2) and sediment yield (Table 5.3) approximately matched the measured ones at the outlets of the watershed. Based on the given threshold areas and manual input data automatic sub-basin delineation was done for the UW and TW. The SWAT model divided the sub-basin into detailed HRUs. The model delineates each HRUs with a user defined threshold based on the percentage of the slope classes, soil type and land use (Arnold et al. 2011).

HRUs (Hydrologic Response Units) for this study were delineated using the soil type and the land use thresholds set at 5% area coverage. Any soil type and land use type each covering more than 5% of the sub-basin area was considered as an HRU. Based on the thresholds selected, there were a total of 760 HRUs in the UW and 658 HRUs in the TW. These HRUs were used for analyses on a particular land use, soil type and slope class.

Table 5.2 List of parameters adjusted for runoff during the calibration process

Parameter name	Description	Fitted value		Range	Rank
		UW[1]	TW[2]		
R__CN2.mgt	Curve number	-0.013	0.065	-0.25–0.25	1
V__RCHRG_DP.gw	Deep aquifer percolation fraction	0.19	0.1	0–0.2	2
V__SURLAG.bsn	Surface runoff lag coefficient	9.33	5.5	1–10	3
V__GW_DELAY.gw	Groundwater delay time (days)	262.5	250	0–500	4
R__SOL_K (1).sol	Saturated hydraulic conductivity	-0.16	-0.17	-0.25–0.25	5
V__REVAPMN.gw	Threshold depth of water in the shallow aquifer percolation to the deep aquifer to occur (mm H_2O)	337	250	0–500	6
V__GW_REVAP.gw	Groundwater “revap” coefficient	0.09	0.17	0–0.2	7
V__CH_N2.rte	Manning’s “n” value for the main channel	0.26	0.15	0–0.3	8
V__ALPHA_BF.gw	Base flow alpha factor (days)	0.23	0.5	0–1	9
V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)	875	833.3	0–5000	10
R__SOL_AWC (1).sol	Soil available water storage capacity	-0.11	-0.17	-0.25– 0.25	11
V__ESCO.hru	Plant uptake compensation factor	0.48	0.84	0.01 –1	12

Table 5.3 List of parameters adjusted for sediment during the calibration process

Parameter name	Description	Fitted value		Range	Rank
		UW	TW		
R__USLE_K.sol	USLE soil erodibility factor	0.17	0.19	0.15–0.35	1
V__USLE_P.mgt	USLE support practice factor	0.79	0.72	-0.01–0.8	2
V__SPEXP.bsn	Exponent parameter for calculating sediment in channel routing.	1.2	1.06	1–1.4	3
V_SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing.	0.02	0.04	0–0.05	4
R__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium	-0.08	-0.11	-0.2–0.2	5
V__CH_N2.rte	Manning's “n” value for the main channel	0.24	0.21	0–0.3	6
V_CH_COV1.rte	Channel erodibility factor	0.29	0.36	0.0–0.5	7
V__CH_COV2.rte	Channel cover factor	0.50	0.55	0.001–1	8

[1] Untreated watershed
[2] Treated watershed

5.2.4. Model Performance Evaluation

Graphical and statistical model evaluation techniques were used to see how well the model simulation matches the observed data. SWAT and SWAT-CUP calibration tools provide multiple model evaluation statistical criteria to be selected as an objective function for model calibration and validation based on the recommendations suggested by Santhi *et al.* (2001) and Moriasi *et al.* (2007). The algorism program SUFI-2 (Sequential Uncertainty Fitting 2) that is linked to SWAT-CUP2012 version 5.1.6.3 was used for a combined model sensitivity analysis, calibration and validation procedures (Abbaspour *et al.,* 2004; Abbaspour *et al.,* 2007). The SUFI-2 algorithm accounts for different sources of input data uncertainty, conceptual model uncertainty and parameter uncertainty (Gupta *et al.,* 2006). For this particular study coefficient of determination (R^2) (Krause *et al.,* 2005), Nash-Sutcliffe Efficiency (NSE) (Nash and Sutcliffe, 1970) and Percent bias (PBIAS) (Gupta *et al.*, 1999) evaluation statistics were used to see the goodness fit of the model related to runoff and sediment yield for the TW and UW watersheds (Santhi *et al*., 2001; Moriasi *et al.,* 2007).The equations used are:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(E_i - \bar{E})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(E_i - \bar{E})^2}}\right]^2 \qquad (1)$$

where, n is the number of observations or samples; O_i is observed values; E_i is estimated values; $\bar{O}$ is mean of observed values; $\bar{E}$ is the mean of estimated values; I is counter for individual observed and predicted values. The R^2 ranges between 0 and 1, where 1 means that the predicted value is equal to the observed value and zero means that there is no correlation between the predicted and observed values.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(E_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad (2)$$

The range of E lies between $-\infty$ and 1.0 with $E = 1$ describing a perfect fit. Values between 0-1.0 are generally viewed as acceptable levels of performance, whereas values <0 indicate that the mean observed value is a better predictor than the model.

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^{n}(O_i - E_i) * 100}{\sum_{i=1}^{n}(O_i)}\right] \qquad (3)$$

The optimal value of PBIAS is 0, with low magnitude values indicating accurate model simulation (Moriasi *et al.,* 2007).

5.3. Results

5.3.1. Model Calibration and Validation

Mean daily runoff discharge and sediment yield data from both watersheds were used to calibrate the SWAT model. Some of the appropriate parameters were adjusted until the predicted daily runoff (Table 5.2) and sediment yield (Table 5.3) were approximately matched the measured ones at the outlets of the watersheds.

5.3.2. Runoff Calibration and Validation

Results showed that the observed mean daily discharge was 0.03 $m^3 s^{-1}$ for the calibration period and 0.02 $m^3 s^{-1}$ for the validation period whereas the estimated mean daily discharge was 0.03 $m^3 s^{-1}$ for the calibrated period and validation period in the UW (Table 5.4). The simulation results showed that the coefficient of determination (R^2) and NSE values for the daily runoff in the UW were 0.77 and 0.75 for the calibration period and 0.72 and 0.56 for the validation period, respectively (Table 5.4). Percent bias (PBIAS) was -8.9 for the calibration and 14.8 for validation for the UW.

Similarly, the estimated and the observed daily discharge for the TW was 0.02 $m^3 s^{-1}$ for the calibration and validation periods (Table 5.4). The daily runoff simulation results showed better model efficiency with a coefficient of determination (R^2) value for the daily runoff 0.78 for the calibration period and 0.70 for the validation period (Table 5.4). The NSE values were 0.63 for calibration and 0.58 for validation periods (Table 5.4). The mean daily results give PBIAS of 29.2 for calibration and 24.3 for the validation periods (Table 5.4) indicating that the model performed well according to Moriasi et al. (2007).

Table 5.4 Mean daily discharge, sediment yield and summary statistics of treated and untreated watersheds

Parameter	Untreated watershed			
	Calibration		Validation	
	Observed (standard deviation)	Simulated (standard deviation)	Observed (standard deviation)	Simulated (standard deviation)
Mean daily discharge ($m^3 s^{-1}$)	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.02 (0.02)
Mean daily sediment yield ($t ha^{-1}$)	4.19 (4.05)	2.86 (4.22)	3.71 (2.46)	2.63 (2.89)
Discharge				
R2	0.77		0.72	
NSE	0.75		0.56	
PBIAS	-8.9		14.2	
Sediment yield				
R2	0.69		0.65	
NSE	0.54		0.33	
PBIAS	29.2		24.3	
	Treated watershed			
Mean daily discharge ($m^3 s^{-1}$)	0.02 (0.02)	0.01 (0.02)	0.02 (0.02)	0.02 (0.03)
Mean daily sediment yield ($t ha^{-1}$)	3.13 (3.10)	2.21 (3.22)	2.07 (1.52)	1.55 (1.69)
Discharge				
R2	0.78		0.70	
NSE	0.63		0.58	
PBIAS	29.2		24.3	
Sediment yield				
R2	0.65		0.55	
NSE	0.47		0.31	
PBIAS	25.4		33.8	

Results showed that there is good agreement between the observed and predicted daily runoff for both treated (TW) and untreated watershed (UW) during calibration and validation periods (Figure 5.5 and Figure 5.6) indicating that SWAT performs well. This indicates that the model predicts the daily discharge very well (Figure 5.5 and Figure 5.6).

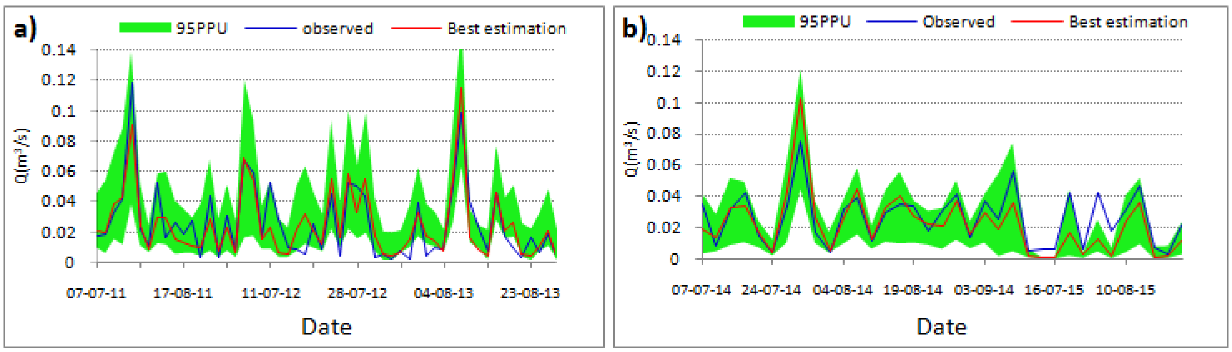

Figure 5.5 Observed and simulated daily runoff for calibration (a) and validation (b) period at the outlet of untreated watershed (UW)

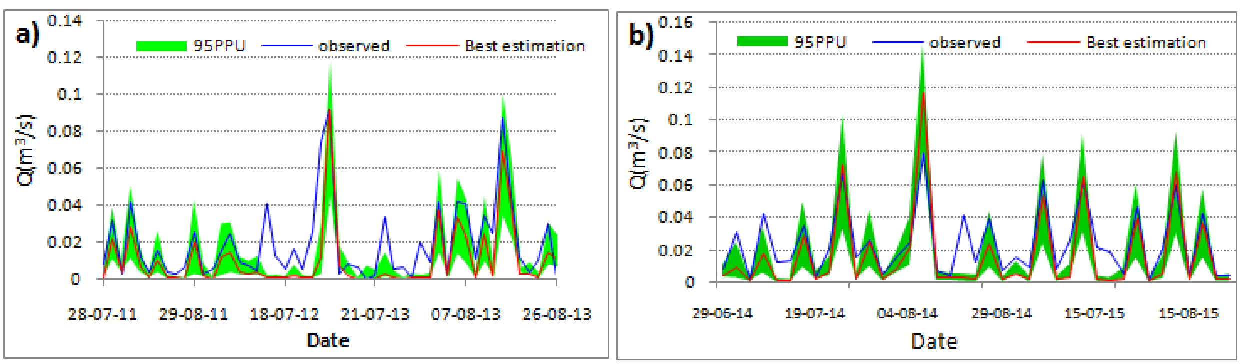

Figure 5.6 Observed and simulated daily runoff for calibration (a) and validation (b) period and at the outlet of the treated watershed (TW)

The observed runoff on the same day was often under predicted for the calibration period and for the validation period. Based on the model results the mean daily runoff from both watersheds shows better agreement with the measured runoff calibration and validation periods (Figure 5.7a and Figure 5.7b). The evaluation coefficients of the simulated daily runoff of different objective functions for both the TW and UW indicated satisfactory model fit according to the assessment criteria (Moriasi et al. 2007). Khelifa et al. (2016) reported daily runoff with NSE value of 0.64 for calibration and 0.68 for validation. Similar studies done are in better agreement with these results (Addis et al. 2016; Zimale et al. 2016). For a study in the Gumara watershed by Zimale et al. (2016), the NSE values for daily flows obtained were 0.70 for calibration and 0.77 for validation period.

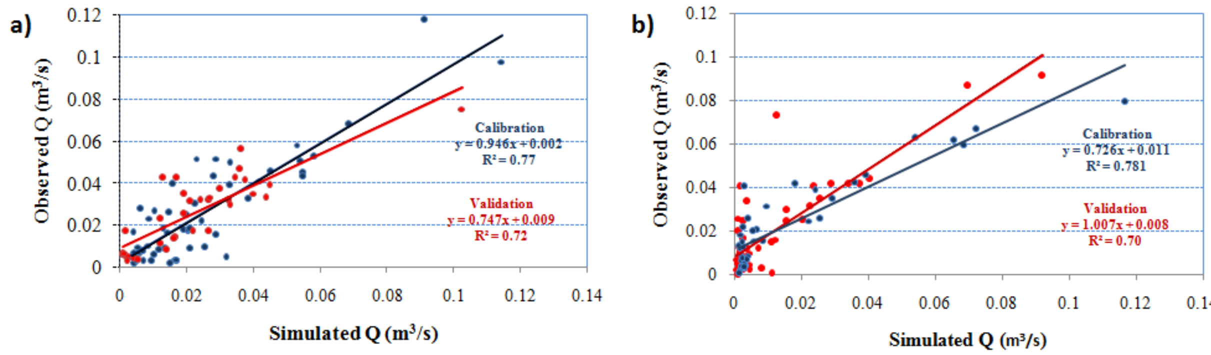

Figure 5.7 Observed and simulated daily discharge (Q) for calibration and validation period at UW (a) and TW (b)

5.3.3. Sediment Calibration and Validation

Daily sediment yield was calibrated and validated using the measured data from the two watersheds. Sediment yield prediction results gave a coefficient of determination (R^2) of 0.69 for calibration and 0.65 for validation period in the UW (Figure 5.8a) and a coefficient of determination (R^2) of 0.65 for calibration and 0.55 for validation period for the TW (Figure 5.8b).

Daily sediment yield calibration and calibration results showed NSE of 0.47 and 0.31, respectively for the TW and 0.54 and 0.33 for calibration and validation, respectively, for the UW (Table 5.4). Results showed that SWAT model under estimated the generated sediment yield. The model predicted about 33.5 t ha^{-1} y^{-1} and 44.8 t ha^{-1} y^{-1} sediment yield for the TW and UW, respectively. The observed sediment yield was 39.9 t ha^{-1} y^{-1} and 64.6 t ha^{-1} y^{-1} in the TW and UW, respectively. The model under predict the annual sediment yield of the TW and the UW. This indicates that there is a potential impact of the SWC on sediment yield reduction on the treated watershed.

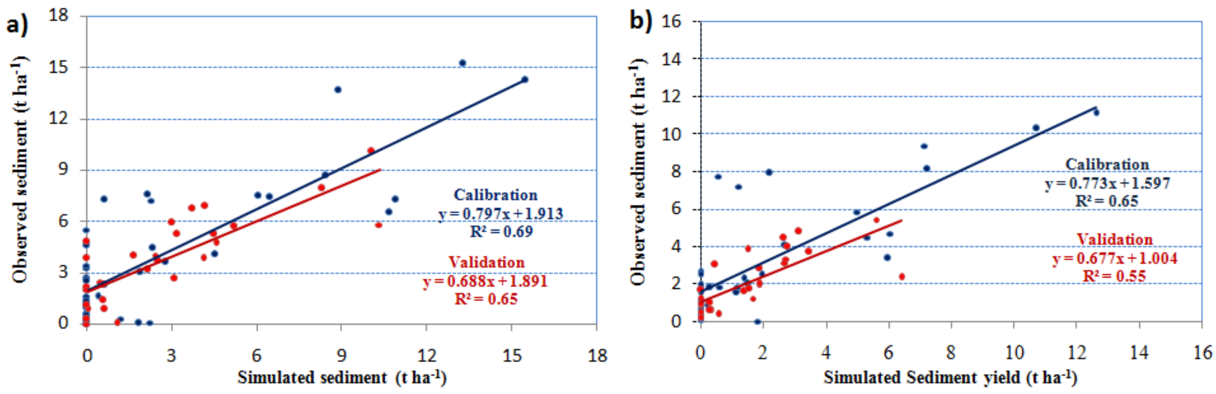

Figure 5.8 Observed and simulated daily sediment for calibration and validation period at UW (a) and TW (b)

5.4. Discussion

The results of the UW (Untreated Watershed) and TW (Treated Watershed) show that the soil and water conservation structures constructed by the farmers reduce the surface runoff and soil losses in the Highlands of Ethiopia. The results show that the untreated watershed had higher sediment and runoff losses than a treated watershed, given similar climatic and land use patterns. The intervention of SWC measures by the mobilization of the community has a significant soil loss reduction to protect their land from the rainfall driven soil erosion. The effectiveness of SWC on runoff and sediment yield reduction has been reported in other studies in the Northern Ethiopia (Desta et al 2005; Nigussie et al. 2005; Descheemaeker et al. 2006; Mitiku et al. 2006; Nyssen et al. 2007, 2009; Dagnew et al. 2015, 2017).

In this study, SWAT was used to assess the impacts of SWC on runoff and erosion processes, and the model has been found a useful tool for understanding the hydrologic processes and the sediment dynamic in the study area in both watersheds. The evaluation coefficients of the simulated daily runoff of the different objective functions for both the TW and UW indicated satisfactory model fit according to the assessment criteria (Moriasi et al. 2007). The NSE values found in the UW and the TW agreed with Khelifa et al. (2016) findings of a daily runoff with NSE value of 0.64 for calibration and 0.68 for validation who has studied the impact of SWC on runoff and sediment yield. In another study in the Gumara watershed by Zimale et al. (2016), the NSE values for daily flows obtained were 0.70 for calibration and 0.77 for validation period, which is comparable with the UW and TW NSE values in the Gumara-maksegnit watersheds. Similar studies done are in better agreement with these results (Addis et al. 2016).

However, the model tends to underestimate sediment yield during calibration and validation period for both watersheds. The NSE for sediment yield in both watersheds showed lower values in the calibration and validation periods. The under estimation of the sediment yield by the model is because, there are parts of the watershed severely eroded which created gully erosion in both watersheds that led to higher soil losses beyond the estimated sediment load. This is substantiated by the photo taken in figure 5.9 which shows the development of deep gully in the upper parts of the watershed that contributes higher soil erosion losses that generate higher sediment load in the outlets.

Figure 5.9 Gully development in the upper part of the watershed (left) runoff with high sediment concentration at the outlets (right)

The model result indicated that SWC structures considerably reduced soil loss by 25-38% in the Gumara-Maksegnit watershed. A plot level experiment conducted on the effects of stone bunds showed that stone bunds can reduce soil erosion by 33-41% (Riederet al. 2014; Klik et al. 2016) in the TW which is close to the current finding of the soil loss reduction level due to SWC. Similarly, Strohmeier et al. (2015) reported that at plot scale stone bunds reduced soil loss by 40% in the Gumara-Maksegnit watershed. In another study conducted in Northern Tunisia on the effects of soil and water conservation structures on sediment load, Khelifa et al. (2016) reported 22% reduction in sediment yield at the watershed scale. Similar studies by Abouabdillah et al. (2014), Yesuf et al. (2015), Addis et al. (2016) and Licciardello et al. (2016) are in agreement with our findings. Betrie et al. (2011) also reported 41% reduction sediment yield in the Blue Nile Basin due to stone bunds. The soil loss reduction (25-38%) in this study due to SWC structures at watershed scale agreed with the findings of Abdouabbdilah et al. (2014) who estimated an overall soil loss reduction by 25%.

The sediment yield estimated by SWAT model for the UW (44.8 t ha^{-1} y^{-1}) and TW (33.5 t ha^{-1} y^{-1}) was in agreement with other studies. Setegn et al. (2010) reported sediment loads of 30-60 t ha^{-1} y^{-1} were exported from the Lake Tana watersheds while Easton et al. (2010) predicted a maximum soil loss of 84 t ha^{-1} y^{-1} in the Gumara watershed. Similarly, Zimale et al. (2016) reported an average sediment yield of 49 t ha^{-1} y^{-1} from Gumara watershed. There are also a number of simulation studies on sediment loads prediction at the gauging stations near Lake Tana (Easton et al. 2010; Setegn et al. 2010; Kaba et al. 2014; Zimale et al. 2016) which confirmed the results of the current study conducted in the Gumara-Maksegnit watershed.

5.5. Conclusions

Soil erosion is a serious problem in the Ethiopian highlands arising from agriculture intensification, deforestation and land degradation. To find erosion hotspot areas and to develop a soil conservation strategy, assessment of soil erosion is a useful tool. Empirical soil erosion modeling can provide a quantitative and consistent approach to estimate runoff and soil erosion under a wide range of conditions to interpret physically with the available inputs. In this study, Soil and Water Assessment Tool (SWAT) has been used to predict the impacts of SWC interventions on runoff and soil loss for two adjacent watersheds in the highlands of Ethiopia. SWAT-CUP (SWAT Calibration and Uncertainty Procedure) has been used to perform calibration and validation of the observed and simulated runoff and soil losses. For UW and TW separate SWAT and SWAT-CUP project was set for daily runoff and sediment yield.

The results of the simulation study showed good model performance for daily runoff prediction at each watershed with acceptable R^2, NSE and PBIAS values. However, the model performance was poor in terms of predicting sediment loss with lower NSE values. Overall, the watershed modeling results indicated that soil and water conservation structures can reduce runoff and soil loss in the Gumara-Maksegnit watershed. Based on the calibrated SWAT model, the soil loss from the TW is found to be lower than the UW. The SWC structures reduced soil losses by 25-38% in the TW as compared to the UW. However, the soil erosion is still severe and above the world tolerable ranges (2-11 t ha^{-1} y^{-1}). Therefore, land management strategies and SWC structures should be improved to achieve more sustainable soil erosion protection for sustainable agriculture for food security in the area. Generally, this study found that SWAT can be applied to other watersheds in the Ethiopian highlands to predict the impact of soil and water conservation structure (SWC) on runoff and soil erosion processes.

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References

Abbaspour KC, Johnson A, Genuchten MT (2004) Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. Vadose Zone J 3:1340-1352.

Abbaspour KC, Vejdani M, Haghighat S (2007) SWATCUP calibration and uncertainty programs for SWAT. In Proc. Intl. Congress on Modelling and Simulation (MODSIM’07), 2007; 1603-1609. L. Oxley and D. Kulasiri, eds. Melbourne, Australia: Modelling and Simulation Society of Australia and New Zealand

Abouabdillah A, White M, Arnold JG, De Girolamo AM, Oueslati O, Maataoui A, Lo Porto A (2014) Evaluation of soil and water conservation measures in a semi-arid river basin in Tunisia using SWAT. Soil Use Manage 30:539–549. DOI: 10.1111/sum.12146.

Adimassu Z, Mekonnen K, Yirga C, Kessler A (2014) Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. Land Degrad Dev 25:554–564. doi:10.1002/ldr.2182, 2014

Addis HK, Strohmeier S, Ziadat F, Melaku ND, Klik A (2016) Modeling streamflow and sediment using SWAT in the Ethiopian Highlands. Int J Agric Biol Eng 9(5):51－66

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment part I: Model development. Journal of the American Water Resources Association 34(1):73－89

Arnold J, Kiniry G, Srinivasan JR, Williams R, Haney JR, Neitsch SL (2011) SWAT input/output file documentation, version 2009. Temple, Texas, USA: Grassland Soil and Water Research Laboratory

Belay KT, Van Rompaey A, Poesen J, Van Bruyssel S, Deckers J, and Amare K (2014) Spatial analysis of land cover changes in eastern Tigray (Ethiopia) from 1965 to 2007: are there signs of a forest transition? Land Degrad Dev 25:130–142. doi:10.1002/ldr.1153, 2014

Betrie GD, Mohamed YA, van Griensven A, Srinivasan R (2011) Sediment management modelling in the Blue Nile Basin using SWAT model. Hydrol. Earth Syst. Sci. 15:807–818

Bonta JV. 1997. Determination of watershed curve number using derived distributions. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers 123(1): 28–36.

Bonta JV (1997) Determination of watershed curve number using derived distributions. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers 123(1): 28–36.

Dagnew DC, Guzman C, Zegeye A, Akal AT, Moges MA, Tebebu AT, Mekuria W, Ayana EK, Tilahun SA, Steenhuis TS (2017) Sediment Loss Patterns in the Sub-Humid Ethiopian Highlands. Land Degrad Dev 28:1795–1805. DOI: 10.1002/ldr.2643

Dagnew DC, Guzman C, Zegeye A, Tibebu TY, Getaneh M, Abate S, Zemale FA, Ayana KE, Tilahun SA, Steenhuis TS (2015) Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: The Debre Mawi watershed. J. Hydrol. Hydromech.63, 2015. DOI: 10.1515/johh-2015-0021

Descheemaeker K, Nyssen J, Rossi J, Poesen J, Mitiku Haile, Moeyersons J, Deckers J (2006c). Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia. Geoderma 132: 291–314

Desta Gebremichael, Nyssen J, Poesen J, Deckers J, Mitiku Haile,Govers G, Moeyersons J (2005). Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray highlands, Northern Ethiopia. Soil UseManage21: 287–297

Di Luzio M, Srinivasan JR, Arnold JG (2002) Integration of watershed tools and SWAT model into BASINS. J American Water Res Assoc 38(4):1127-1141

Easton ZM, Fuka DR, White ED, Collick AS, Asharge B, McCartney M, Awulachew SB, Ahmed AA, Steenhuis TS(2010) A multi-basin SWAT model analysis of runoff and sedimentation in the Blue Nile, Ethiopia. Hydrol. Earth System Sci. Discussions **7**:3837-3878

Erkossa T, Wudneh A, Desalegn B, Taye G (2015) Linking soil erosion to on-site financial cost: lessons from watersheds in the Blue Nile basin. Solid Earth 6:765–774. DOI:10.5194/se-6-765-2015

Ganasri BP, Ramesh H (2015) Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. Geosciences Frontiers 7:953-961

Gassman PW, Reyes MR, Green CH, Arnold JG (2007) The Soil and Water Assessment Tool: Historical development, applications, and future research directions. Trans ASABE 50(4):1211–1250

Grum B, Woldearegay K, Hessel R , Baartman EM , Abdulkadir M, Yazewe E , Kessler A , Ritsema CJ , Geissen V (2017) Assessing the effect of water harvesting techniques on event-based hydrological responses and sediment yield at a catchment scale in northern Ethiopia using the Limburg Soil Erosion Model (LISEM). Catena.159:20-34. Doi: 10.1016/j.catena.2017.07.018

Gupta HV, Sorooshian S, Yapo PO (1999) Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. J. Hydrol. Eng. 4(2):135－143

Gupta HV, Beven KJ, Wagener T (2006) Model calibration and uncertainty estimation. In Encyclopedia of Hydrological Sciences, pp 11－131

Guzman C, Tilahun SA, Dagnew DC, Zegeye A, Tebebu TY, Yitaferu B, Steenhuis TS (2017) Modeling sediment concentration and discharge variations in a small Ethiopian watershed with contributions from an unpaved road. J. Hydrol. Hydromech., 65, 2017, 1, 1–17. DOI: 10.1515/johh-2016-0051

Kaba E, Philpot W, Steenhuis T (2014) Evaluating suitability of MODIS-Terra images for reproducing historic sediment concentrations in water bodies: Lake Tana, Ethiopia. Int. J. Appl. Earth Observ. Geo-Inf. 26:286-297

Kebede W (2014) Effect of Soil and Water Conservation Measures and Challenges for its Adoption: Ethiopia in Focus. J. Environ. Sci. Technol. 7:185-199

Keesstra S, Pereira P, Novara A, Brevik EC, Azorin-Molina C, Parras-Alcántara L, Jordán A, Cerdà A (2016) Effects of soil management techniques on soil water erosion in apricot orchards. Sci.Total Environ. 551–552: 357–366. doi:10.1016/j. scitotenv.2016.01.182

Khelifa WB, Hermassi T, Strohmeier S, Zucca C, Ziadat F, Boufaroua M, Habaieb H (2016) Parameterization of the Effect of Bench Terraces on Runoff and Sediment Yield by SWAT Modeling in a Small Semi-arid Watershed in Northern Tunisia. Land Degrad. Dev. doi: 10.1002/ldr.2685

Klik A, Wakolbinger S, Obereder E, Strohmeier S, Melaku ND (2016) Impacts of Stone Bunds on Soil Loss and Surface Runoff: A Case Study from Gumara-Maksegnit Watershed, Northern Ethiopia. AgroEnviron 2016, Purdue University, Wets Lafayette, IN; 06/2016

Krause P, Boyle DP, Base F (2005) Comparison of different efficiency criteria for hydrological model assessment. Adv.Geosci. 5:89－97

Licciardello F, Toscano A, Cirelli GL, Consoli S, Barbagallo S (2016) Evaluation of Sediment Deposition in a Mediterranean Reservoir: Comparison of Long Term Bathymetric Measurements and SWAT Estimations. Land Degrad. Develop doi: 10.1002/ldr.2557

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50(3) 885－900

Mitiku H, Herweg K, Stillhardt B (2006) Sustainable Land Management – A New Approach to Soil and Water Conservation in Ethiopia. Mekelle, Ethiopia: Land Resources Management and Environmental Protection Department, Mekelle University; Bern, Switzerland: Centre for Development and Environment (CDE), University of Bern, and Swiss National Centre of Competence in Research (NCCR) North-South. 269 pp

Nash JE, Sutcliffe JV (1970)River flow forecasting through conceptual models: Part I. A discussion of principles. J. Hydrol. 10(3):282－290

Neitsch SL, Arnold JG, Kiniry JR, Williams JR (2005) Soil and Water Assessment Tool–Theoretical Documentation, Version 2005.Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Black land Research Center, Texas Agricultural Experiment Station, Texas., USA.

Nigussie Haregeweyn, Poesen J, Nyssen J, Verstraeten G, de Vente J,Govers G, Deckers S, Moeyersons J(2005). Specific sediment yield in Tigray-Northern Ethiopia: assessment and semi-quantitative modelling. Geomorphology 69: 315–331

Nigussie Z, Tsunekawa A, Haregeweyn N, Adgo E, Nohmi M, Tsubo M, Aklog D, Meshesha, DT, Abele S (2017) Farmers' Perception about Soil Erosion in Ethiopia. Land Degrad. Develop 28:401–411. doi:10.1002/ldr.2647

Nyssen J, Poesen J, Mitiku H, Moeyersons J, Deckers J (2000) Tillage erosion on slopes with soil conservation structures in the Ethiopian highlands. Soil Till Res. 57(3): 115–127

Nyssen J, Poesen J, Gebremichael D, Vancampenhout K, D'aes M, Yihdego G, Govers G, Leirs H, Moeyersons J, Naudts J, Haregeweyn N, Mitiku H, Deckers J (2007) Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia. Soil Till Res. 94:151–163

Nyssen J, Clymans W, Poesen J, Vandecasteele I, De Baets S, Haregeweyn N, Naudts J, Hadera A, Moeyersons J, Haile M (2009). How soil conservation affects the catchment sediment budget- a comprehensive study in the north Ethiopian highlands. Earth Surf. Process Landf. 34:1216–1233

Poitras V, Sushama L, Seglenieks F, Khaliq MN, Soulis E (2011) Projected changes to streamflow characteristics over Western Canada as simulated by the Canadian RCM. J. Hydrometeorol 12(6):1395–1413

Rieder J, Strohmeier S, Melaku ND, Ziadat F, Klik A (2014) Investigation of the impact of stone bunds on water erosion in northern Ethiopia. Geophysical Research Abstracts Vol. 16, EGU2014-3885, 2014. EGU General Assembly 2014, Austria, Vienna

Santhi C, Arnold JG, Williams JR, Dugas WA, Hauck L (2001) Validation of the SWAT model on a large river basin with point and nonpoint sources. J Am Water Res Assoc. 37(5):1169-1188

Setegn SG, Srinivasan R, Melesse AM, Dargahi B (2010) SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia. Hydrol Process 24:357-367

Schuol J, Abbaspour KC (2007) Using monthly weather statistics to generate daily data in a SWAT model application to West Africa. Ecol Model 201(3):301−311

Strohmeier S, Rieder J, Kaltenleithner M, Melaku ND, Guzmán G, Ziadat F, Andreas Klik A (2015) Using magnetite tracer to evaluate a novel plot experimental design for the assessment of soil and water conservation impacts of stone bunds in Ethiopia. EGU General Assembly 2015; 04/2015

Sunday EO, Mohammed MB, John CN, Hermansah YW, Charles A Toshiyuki W (2012) Soil degradation-induced decline in productivity of sub-Saharan African soils: the prospects of looking downwards the lowlands with the Sawah ecotechnology, Appl. Environ. Soil Sci. doi:10.1155/2012/673926, 2012

Taguas EV, Guzmán E, Guzmán G, Vanwalleghem T, Gómez JA (2015) Characteristics and importance of rill and gully erosion: a case study in a small catchment of a marginal olive grove. Cuadernos de Investigación Geográfica, 41–20. doi:10.18172/cig.2644

Teshome A, de Graaff J, Ritsema C, Kassie M (2016) Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land management in the north western Ethiopian highlands. Land Degrad. Dev. 27:884–898. doi:10.1002/ldr.2298

Vancampenhout K, Nyssen J, Gebremichael D, Deckers J, Poesen J, Haile M, Moeyersons J (2006) Stone bunds for soil conservation in the northern Ethiopian highlands: Impact on soil fertility and crop yield. Soil Till Res. 90:1-15

Verstraeten G, Poesen J, Demare´e G, Salles C (2006) Long-term (105 years) variability in rain erosivity as derived from 10-min rainfall depth data for Ukkel (Brussels, Belgium):

Implications for assessing soil erosion rates, J. Geophys. Re s.111, D22109, doi:10.1029/2006JD007169

Yesuf HM, Assen M, Alamirew T, Assefa M. Melesse AM (2015) Modeling of sediment yield in Maybar gauged watershed using SWAT, northeast Ethiopia. Catena 120:191-205

ZehetbauerI,Strohmeier S, Ziadat F, Klik A (2013) Runoff and sediment monitoring in an agricultural watershed in the Ethiopian Highlands. Geophysical Research Abstracts, 2013; vol. 15, p. 5640. EGU General Assembly 2013, Austria, Vienna

Zimale FA, Mogu MA, Alemu ML, Ayana EK, Demissie SS, Tilahun SA, and Steenhuis TS (2016) Calculating the sediment budget of a tropical lake in the Blue Nile basin: Lake Tana, SOIL Discuss.doi:10.5194/soil-2015-84, 2

6. Effect of nitrogen fertilizer rate and timing on sorghum productivity in Ethiopian highland Vertisols

Abstract

Sorghum is cultivated on Vertisols in the Ethiopian Highlands. An experiment was conducted in the Gumara-Maksegnit watershed in 2013 and 2014 to assess the effect of rate and timing of nitrogen fertilizer application on the possibility to shorten the maturity period and to improve the productivity of sorghum. The experiment was laid out as Randomized Complete Block Design with three replications. Treatments were nitrogen doses between 0 and 87 kg N ha^{-1} as urea applied at planting, at knee-height stage or in split doses at both stages. Results showed that application of 23, 41, 64 and 87 kg ha^{-1} N gave a yield increase of 40, 53, 62 and 69% over the control (0 kg N ha^{-1}), respectively. In addition, split application of 41 kg ha^{-1}, 64 kg ha^{-1} and 87 kg ha^{-1} of nitrogen fertilizer, half at planting and half at knee height stage, gave 19%, 15% and 18% increase in sorghum grain yield over a single dose application, respectively. Applying 87 kg ha^{-1} nitrogen fertilizer with split application half at planting and half at knee height stage, along with 46 kg ha^{-1} of P_2O_5, gave the highest grain yield and income.

Keywords: waterlogging, nitrogen, Vertisols, sorghum, Split application

6.1. Introduction

Vertisols (heavy black clay soils) cover about 43 million hectares comprising 19% of total land area in sub Saharan Africa (Gezahegn 2001). Nearly 30% of the Vertisols area is located in the Ethiopian highlands which cover about 8 million hectares (Wubie 2015). Vertisols are productive soils. However, these soils are difficult to manage due to their poor internal drainage. These soils are prone to flooding and waterlogging during the rainy season. Owing to water logging cultivated Vertisols in Ethiopia often give relatively low crop yields (Gezahegn 2001). Therefore, in a country affected by food deficit like Ethiopia, proper management of Vertisols are believed to improve crop productivity for food security (Wubie 2015).

Sorghum (*Sorghum bicolor* L.) is the most important staple crop for the farmers in North Gonder zone where Vertisols are dominant soils. However, sorghum productivity in Ethiopia is far below its potential. In areas where sorghum is commonly grown, crop yield ranges from 3 to 4 t ha^{-1} (Gebremariam and Assefa 2015). The major factors that accounts for this low yield are moisture stress, low soil fertility and pest damage. On Vertisols the maturity period of sorghum is delayed, mostly taking more than seven months, due to waterlogging. During July and August, the crop remains stunted with yellow leaves and stems. Previous studies have reported negative effects of waterlogging on sorghum, maize and wheat (Promkhambut et al. 2010; Araki et al. 2012). Furthermore, local farmers traditionally don't use fertilizer or weed sorghum fields until the soil starts drying in September. Thus the crop remains stressed in July, August and part of September due to the combined effects of waterlogging, weed infestation and limited fertilizer application. Crop growth mainly occurs in mid-September when the rain stops and the soil starts drying. This situation leads the crop to be confronted with moisture deficits and longer exposure to bird damage as the rest of the crops are harvested in October and November while sorghum remains in the field until the end of January.

The local extension service advised farmers to shift from sorghum to wheat and teff production on Vertisols. However, farmers consider sorghum as irreplaceable due to its food, feed, local drink and fuel wood values. Though sorghum yield is as low as 1.2 t ha^{-1} farmers prefer growing sorghum because of its multiple benefits. These benefits could be largely enhanced if farmers adopted a sound fertilization strategy, along with drainage and weeding practices. Therefore, fertilizers are needed to replace nutrients which are exported and lost during cropping to maintain a positive nutrient balance. However, most smallholder farmers in tropical Africa rarely use inorganic fertilizers on food crops including sorghum. Subsistence farming in Sub-Saharan Africa is thus characterized by low external input, low crop yield, food insecurity, nutrient mining and environmental degradation (Mafongoyaet al. 2006). The objective of this study was to assess the effects of the rate and timing of nitrogen fertilizer application on the possibility of decreasing the maturity period while increasing the productivity of sorghum on the Vertisols of the Gumara-Maksegnit watershed.

6.2. Materials and Methods

6.2.1. Description of the study area

The study was conducted in Gumara-Maksegnit watershed, Lake Tana basin, Ethiopia (Figure 7.1). The watershed is located between 12° 23’ 53” and 12° 30’ 49” Latitude North and between 37° 33’ 39” and 37° 37’ 14” Longitude East. The elevation of the study area ranges from 1920 to 2400 meter above sea level.

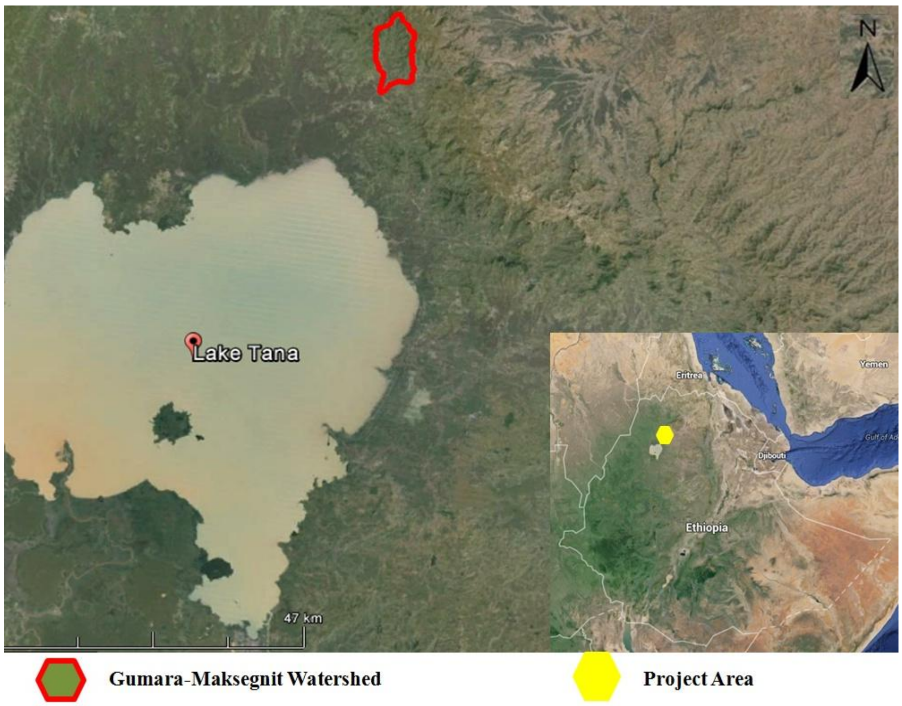

Figure 6.1Map of the study area

The mean minimum and maximum monthly temperatures (1997 to 2014) of the area are 13.3 °C and 28.5 °C, respectively (Demelash et al. 2014). Daily rainfall data were recorded from the station installed in the watershed. The long term (1997 to 2014) annual mean rainfall in the watershed is 1152 mm. The total annual rainfall in 2013 and 2014 was 1276 mm and 1119 mm respectively, of which more than 90% occurred from June to September. In both years the maximum rainfall was recorded in July and August, when the sorghum crop is at early stages resulting in waterlogging. The total rain in the growing period (June to January) was 1258 mm in 2013, with 53 rainy days, and 1103 mm in 2014 with 55 rainy days (Table 6.1).

Table 6.1 Monthly rainfall of the growing season at Gumara-Maksegnit watershed station

Months	June	July	August	September	October	November	December	January
				2013				
Rainfall (mm)	172.4	394.8	387	254.6	39	10.4	0	0
Rainy days	7	19	13	9	4	1	0	0
Months (%)	13.5	30.9	30.3	19.6	3.1	0.8	0	0
				2014				
Rainfall (mm)	115.4	387.8	371.6	156.8	57.6	14.0	0	0
Rainy days	8	16	21	11	3	1	0	0
Months (%)	10.3	34.6	33.2	14	5.2	1.3	0	0

6.2.2. Soil Sampling and Analysis

Prior to planting surface (0 - 40 cm) soil samples were collected from five spots across the experimental field. The samples were thoroughly mixed, air dried and ground to pass 2 mm sieve to determine soil physical and chemical parameters. Soil texture was determined using Bouyoucos hydrometer method (Tisdale et al. 1993). Available P was extracted with sodium bicarbonate solution at pH 8.5 following the procedure described by Olsen et al. (1954). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method as described by Jackson (1958). Soil pH was measured potentiometrically in the supernatant suspension of a 1:2.5 soil:water mixture using a pH meter according to the method outlined by Sahlemedhin and Taye (2000). Organic carbon was determined following the Walkley and Black wet oxidation method as described by Jackson (1958). The soil CEC was determined at pH 7 after displacement of the cations by using 1 N ammonium acetate; thereafter, the ammonium was estimated titrimetrically by distillation of ammonium that was displaced by sodium following the procedure of Sahlemedhin and Taye (2000). Total exchangeable bases were determined after leaching the soils with ammonium acetate; Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer and K^{+} and Na^{+} were analyzed flame photometrically following the procedure of Sahlemedhin and Taye (2000).

The soil of the experimental field is clay textured with a clay content of 56% (Table 6.2). The soil has low organic matter content (less than 4%). The soil has a medium CEC (61.86 cmol kg^{-1}) according to Landon (1991) and low available P content (3.42 mg kg^{-1}) according to Olsen et al. (1954). The pH is 7.07, within the suitable range for sorghum production which is 6 to 8 (Landon 1991).

Table 6.2 Initial soil physical and chemical properties of the experimental site

Soil properties	
pH	7.07
Available P (ppm)	3.42
Organic matter (%)	2.35
CEC cmol(+)kg^{-1}	61.86
Exchangeable Ca, cmol(+)kg^{-1}	38.42
Exchangeable Mg, cmol(+)kg^{-1}	21.19
Exchangeable K, cmol(+)kg^{-1}	2.42
Exchangeable Na, cmol(+)kg^{-1}	0.28
Texture	Clay
Silt (%)	19
Clay (%)	56
Sand (%)	25

6.2.3. Experimental design

The on-farm experiment was conducted in the 2013 and 2014 cropping seasons. The experiment comprised of eleven treatments in a Randomized Complete Block Design (RCBD) with three replications. A local sorghum variety (*'Bulie'*) was sown at the onset of rains (June 10, 2013 and June 13, 2014). Treatments were nitrogen doses between 0 and 87 kg N ha^{-1} as urea applied at planting, at knee-height stage or in split doses at both stages (Table 6.3). Phosphorus (Triple Super Phosphate, TSP and Di-ammonium phosphate, DAP) was also applied at planting at the rate of 46 kg P_2O_5 ha^{-1} and 18 kg N ha^{-1}, uniformly for all plots. Plot size was 3.75 m × 4 m. Standard spacing of 75 cm row spacing and 25 cm plant spacing was used (Aleminew et al. 2015). Seeds were initially sown on flat bed and drainage ridges (40 cm width and 15 cm depth) between sorghum rows were constructed three weeks after sowing to facilitate drainage of excess water (Jutzi et al. 1988). Plots were kept weed free by hand weeding performed 21, 35 and 55 days after planting. No insecticide or fungicide was applied as there was no serious incident of insect pests or diseases.

Table 6.3 Treatment arrangement

Nitrogen rate (kg ha^{-1})	N split application time	Treatment designation
0	Control	0
23	N applied all at planting	$23N_{1+0}$
41	N applied all at planting	$41N_{1+0}$
41	N applied half at planting and the remaining half at knee height stage	$41N_{0.5+0.5}$
41	N applied all at knee height stage	$41N_{0+1}$
64	N applied all at planting	$64N_{1+0}$
64	N applied half at planting and the remaining half at knee height stage	$64N_{0.5+0.5}$
64	N applied all at knee height stage	$64N_{0+1}$
87	N applied all at planting	$87N_{1+0}$
87	N applied half at planting and the remaining half at knee height stage	$87N_{0.5+0.5}$
87	N applied all at knee height stage	$87N_{0+1}$

Plant height and tiller number from five randomly selected plants and panicle length from 10 randomly selected plants were determined from the central rows in each plot. Grain and stover yield were determined from the central three harvestable rows of 7.875 m^2 (2.25 m × 3.5 m) plot size to remove the border effect after air drying until constant weight was obtained. The weight of 1000 seeds was determined by carefully counting the small grains from the harvested plots and weighed with a sensitive balance.

6.2.4. Statistical Analysis

All the collected sorghum yield and yield related data was analyzed using the SAS statistical program (SAS V9.1, SAS Institute Inc., Cary, NC, USA). Whenever the ANOVA detected significant differences between treatments mean separation was conducted using Tukey's test. Economic analysis was done following the CIMMYT partial budget analysis procedure (CIMMYT 1988). Total variable costs (TVC), gross benefit and net benefit were calculated. Net benefit was calculated as the difference between gross benefit and TVC. The price of grain sorghum was US$ 0.375 k g^{-1} and the stover price was US$ 10.0 t^{-1}. The prices of Di-ammonium phosphate (DAP), TSP and urea were US$ 0.78, 0.71 and 0.65 kg^{-1}, respectively. Labor cost for crop management and fertilizer application was US$ 1.75 per man-day. Grain and stover yields were adjusted downward by 10% assuming that farmers will obtain yields 10% lower than obtained by researchers. Then treatments were listed in order of increasing total costs that vary and dominance analysis was done. Sensitivity analysis was done considering 15% variable cost increase and a 5% decrease in sorghum grain yield.

6.3. Results

6.3.1. Sorghum growth and development

Results showed statistically significant differences ($P<0.05$) in plant growth and development. Days to maturity, plant height, panicle length and effective tiller number per plant were significantly affected by treatments (Table 6.4). Plants in the control treatment were significantly ($P<0.05$) delayed in maturity by 37- 40 days compared to plants that received nitrogen fertilizer (Table 6.4). However, there was no statistically significant difference ($P > 0.05$) among treatments in which fertilizer was applied. Differences between nitrogen fertilizer rates and time of application on days to maturity were significant ($P < 0.05$) indicating that applying even the lowest nitrogen fertilizer rate (23 kg N ha^{-1}) could reduce the sorghum maturity period by more than a month. Plant height in the control plot was significantly ($P < 0.05$) shorter by 27-45 cm from sorghum that received nitrogen fertilizer (Table 6.4).

Panicle length is one of the attributes of sorghum that contributes to the grain yield. The analysis of the results showed that sorghum panicle length was significantly ($P<0.05$) influenced by the rate of nitrogen fertilizer and the time of application (Table 6.4). The interaction effect of nitrogen fertilizer with time of application showed significant differences ($P < 0.05$) in panicle length (Figure 6.3a). Split application of nitrogen fertilizer, half at planting and half at knee height stage, gave 8–20% higher sorghum panicle length (Figure 6.3a). The highest panicle length was obtained at the application of 87 kg ha^{-1} nitrogen fertilizer with split application of half at planting and half at knee height stage (Table 6.4).

Table 6.4 Effect of rate and time of nitrogen fertilizer application on sorghum growth at Gumara-maksegnit watershed in 2013 and 2014

Treatment	Days to maturity	Plant height (cm)	Panicle length (cm)	Effective tiller per plant
0	209^{a}	141^{g}	7.8^{g}	1.2^{e}
$23N_{1+0}$	172^{b}	153^{f}	16.8^{f}	2.5^{d}
$41N_{1+0}$	171^{b}	168^{cde}	21.9^{e}	3.0^{cd}
$41N_{0.5+0.5}$	168^{bc}	169^{cd}	27.5^{cd}	4.7^{ab}
$41N_{0+1}$	168^{bc}	160^{ef}	23.0^{e}	3.4^{cd}
$64N_{1+0}$	170^{b}	169^{cd}	26.4^{d}	4.1^{cd}
$64N_{0.5+0.5}$	169^{bc}	164^{de}	31.2^{ab}	4.9^{ab}
$64N_{0+1}$	170^{b}	167^{de}	26.9^{d}	4.3^{cd}
$87N_{1+0}$	169^{bc}	176^{bc}	30.2^{bc}	4.3^{cd}
$87N_{0.5+0.5}$	169^{bc}	178^{b}	33.9^{a}	5.7^{a}
$87N_{0+1}$	172^{b}	186^{a}	31.2^{ab}	4.4^{bc}
LSD	3.01	9.44	4.73	1.96

Note: N_{1+0} denotes all Nitrogen fertilizer applied at planting, $N_{0.5+0.5}$ denotes half nitrogen applied at planting and half at knee height stage and N_{0+1} denotes all nitrogen fertilizer applied at knee height stage. Means within a column followed by the same letter(s) are not significantly different at $P \leq 0.05$.

The number of effective tiller per plant was significantly affected by both nitrogen rate and time of split application ($P < 0.05$). Figure 3b depicts the interaction effect of nitrogen rate and time of split application on effective tiller of sorghum. Higher effective tiller per plant was observed in the application of half nitrogen fertilizer at planting and half at knee height stage in all the nitrogen fertilizer rates (Figure 7.3b). Split application of 41 kg ha^{-1}, 64 kg ha^{-1} and 87 kg ha^{-1} of nitrogen fertilizer, half at planting and half at knee height stage, gave 1.7, 1.0 and 1.4 fold increases in average effective tiller number per plant over a single dose application, respectively. Figure 6.2 shows typical differences between farmers' managed and researcher's managed sorghum fields which were planted on the same date.

Figure 6.2 Farmer's managed (a'), and researcher's managed (b') sorghum fields at flowering

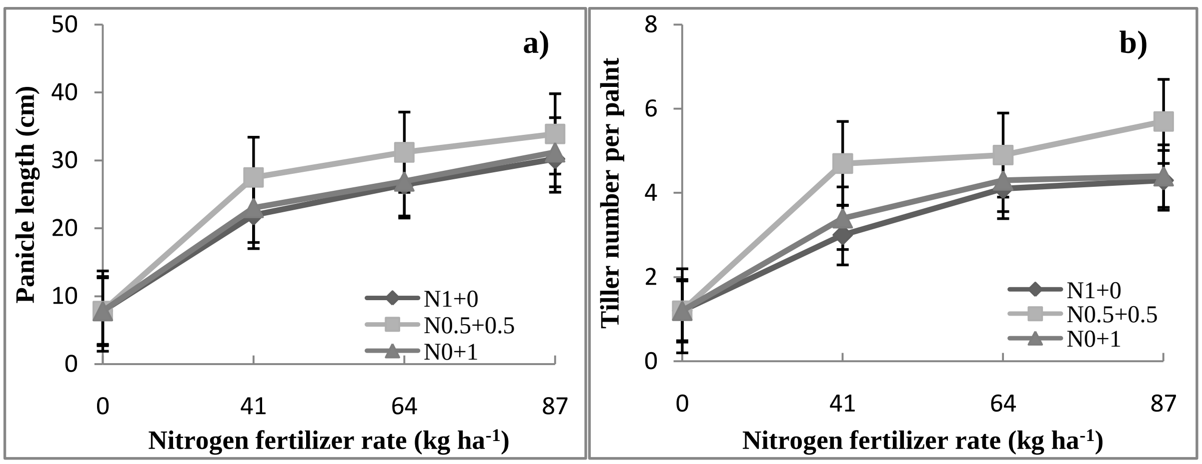

Figure 6.3 Effect of rate and time of nitrogen fertilizer application on panicle length (a) and effective tiller number per plant (b)

6.3.2. Grain and stover yield and thousand seed weight

Grain yield, stover yield and thousand grain weights were significantly ($P < 0.05$) affected by treatments (Table 7.5). Grain and stover yields were significantly higher with application of 87 kg N ha^{-1} half at planting and half at knee height stage as compared to other treatments (Table 7.5). Sorghum grain yield in the control treatments were significantly lowered by 767-2857 kg ha^{-1} from the significantly highest yield (4046 kg ha^{-1}).

Table 6.5 Effect of rate and time of nitrogen fertilizer application on sorghum yield at Gumara-maksegnit watershed in 2013 and 2014

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	1000 seed weight (g)
0	1189^{h}	3696^{f}	32.5^{e}
23N_{1+0}	1756^{g}	6274de	34.5^{de}
41N_{1+0}	1956^{g}	6462^{d}	36.3^{abcd}
41$N_{0.5+0.5}$	2534^{cde}	7874^{bc}	37.6^{ab}
41N_{0+1}	2127^{fg}	6942^{d}	37.4^{ab}
64N_{1+0}	2626^{cde}	8318^{c}	37.2^{abc}
64$N_{0.5+0.5}$	3114^{bc}	9548^{b}	37.9^{a}
64N_{0+1}	2761^{def}	9143^{bc}	35.3^{cd}
87N_{1+0}	3155^{bc}	9657^{b}	34.5^{de}
87$N_{0.5+0.5}$	4046^{a}	11220^{a}	38.2^{a}
87N_{0+1}	3341^{b}	10897^{ab}	36.9^{abc}
LSD	502.89	1820.5	2.02

Note: N_{1+0} denotes all Nitrogen fertilizer applied at planting, $N_{0.5+0.5}$ denotes half nitrogen applied at planting and half at knee height stage and N_{0+1} denotes all nitrogen fertilizer applied at knee height stage. Means within a column followed by the same letter(s) are not significantly different at $P \leq 0.05$.

The interaction effect of nitrogen fertilizer rate and split application showed the relationship of these factors on sorghum grain yield (Figure 6.4a). The grain yield increased with an increase of the rate of nitrogen across the split application. Split application of 41 kg ha^{-1}, 64 kg ha^{-1} and 87 kg ha^{-1} of nitrogen fertilizer, half at planting and half at knee height stage, gave 19%, 15% and 18% increase in sorghum grain yield over a single dose application, respectively (Figure 6.4a).

Similarly, sorghum stover yield was significantly higher with application of 87 kg N ha^{-1} half at planting and half at knee height stage as compared to other treatments (Table 6.5). The split application of nitrogen fertilizer showed statistically significant ($P < 0.05$) differences with the amount of nitrogen fertilizer with respect to stover yield (Figure 7.4b). The analysis of the results showed that split application gave higher stover yield than applying all fertilizer once. Thousand grain weights significantly ($P < 0.05$) increased with nitrogen fertilizer application compared to the control (Tables 6.5). However, the interaction effect of nitrogen fertilizer rate and split application showed non-significant differences ($P > 0.05$).

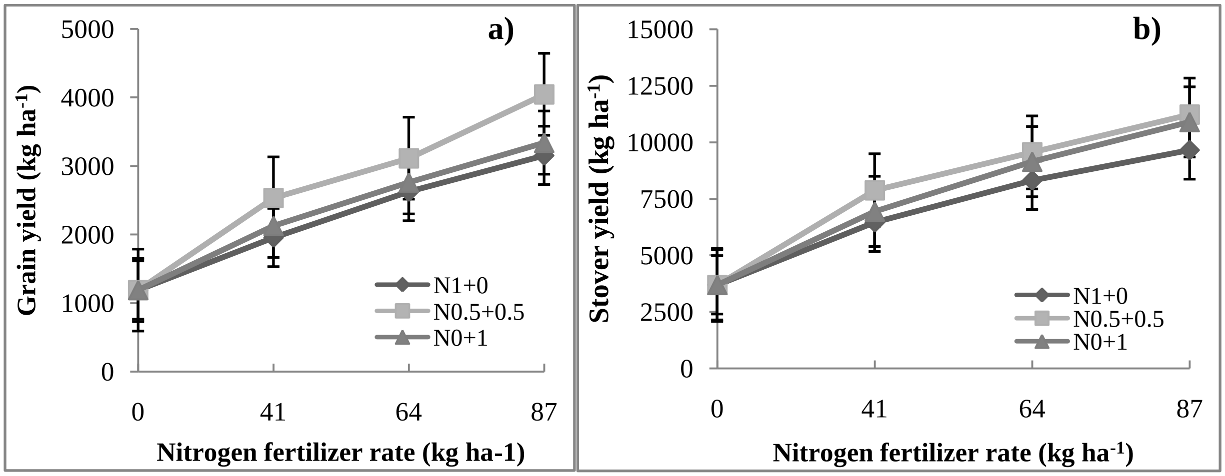

Figure 6.4 Effect of rate and time of nitrogen fertilizer application on sorghum grain yield (a) and stover yield (b)

6.3.3. Economic analysis

Economic analysis was done to identify the most profitable nitrogen fertilizer rate and application time. The partial budget analysis showed that application of 87 kg ha^{-1} of N with split application is economically profitable for sorghum production as it gives a rate of return above 100 % acceptable rate of return (Table 6.6), with the highest MRR (1207 %). This result indicates that for each US$ 1.00 additional investment on fertilizer farmers can earn a return of US$ 12.00. Similarly the sensitivity analysis showed that, considering a situation at which the variable cost would rise by 15% and the price of sorghum was drop by 5%, application of 87 kg ha^{-1} of N with split application still give the highest MRR (981%) (Table 6.7).

Table 6.6 Partial budget analyses for the effect of rate and split application of nitrogen fertilizer on sorghum on Vertisol in Gumara-maksegnit watershed in 2013 and 2014

N Fertilizer (kg ha^{-1})	P Fertilizer (kg ha^{-1})	Grain yield (kg ha^{-1})	Adjusted grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Adjusted Stover yield (kg ha^{-1})	Gross field benefit (US$ ha^{-1})	Total cost that vary (US$ ha^{-1})	Net benefit (US$ ha^{-1})	MRR (%)
0	0	1189.0	1070.1	3696.0	3326.4	434.5	5.6	428.9	
$23N_{1+0}$	10	1756.0	1580.4	6274.0	5646.6	704.4	133.1	571.3	111
$41N^{1+0}$	10	1956.0	1760.4	6462.0	5815.8	906.5	172.4	734.1	415
$41N^{0+1}$	10	2127.0	1914.3	6942.0	6247.8	896.1	172.4	723.7	
$41N_{0.5+0.5}$	10	2534.0	2280.6	7874.0	7086.6	944.4	178.1	766.3	740
$64N_{1+0}$	10	2626.0	2363.4	8318.0	7486.2	978.0	204.9	773.2	
$64N_{0+1}$	10	2761.0	2484.9	9143.0	8228.7	1133.2	204.9	928.4	
$64N_{0.5+0.5}$	10	3114.0	2802.6	9548.0	8593.2	1235.2	221.6	1013.6	509
$87N_{1+0}$	10	3155.0	2839.5	9657.0	8691.3	1291.6	242.4	1049.3	172
$87N_{0+1}$	10	3341.0	3006.9	10897.0	9807.3	1339.1	242.4	1096.7	
$87N_{0.5+0.5}$	10	4046.0	3641.4	11220.0	10098	1466.5	252.1	1214.4	1207

Table 6.7 Sensitivity analyses for the effect of rate and split application of nitrogen fertilizer on sorghum on Vertisol in Gumara-maksegnit watershed in 2013 and 2014

N Fertilizer (kg ha^{-1})	P Fertilizer (kg ha^{-1})	Grain yield (kg ha^{-1})	Adjusted grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Adjusted Stover yield (kg ha^{-1})	Gross field benefit (US$ ha^{-1})	Total cost that vary (US$ ha^{-1})	Net benefit (US$ ha^{-1})	MRR (%)
0	0	1189.0	1070.1	3696.0	3326.4	414.45	6.5	408.0	
$23N_{1+0}$	10	1756.0	1580.4	6274.0	5646.6	671.38	153.1	518.3	111
$41N^{1+0}$	10	1956.0	1760.4	6462.0	5815.8	864.85	198.2	666.6	329
$41N^{0+1}$	10	2127.0	1914.3	6942.0	6247.8	854.31	198.2	656.1	
$41N_{0.5+0.5}$	10	2534.0	2280.6	7874.0	7086.6	900.65	204.8	695.8	601
$64N_{1+0}$	10	2626.0	2363.4	8318.0	7486.2	933.16	235.6	697.6	25
$64N_{0+1}$	10	2761.0	2484.9	9143.0	8228.7	1080.83	235.6	845.2	
$64N_{0.5+0.5}$	10	3114.0	2802.6	9548.0	8593.2	1177.60	254.9	922.7	402
$87N_{1+0}$	10	3155.0	2839.5	9657.0	8691.3	1231.89	278.7	953.2	128
$87N_{0+1}$	10	3341.0	3006.9	10897.0	9807.3	1277.01	278.7	998.3	
$87N_{0.5+0.5}$	10	4046.0	3641.4	11220.0	10098	1398.23	289.9	1108.3	981

6.4. Discussion

Waterlogging is a serious environmental stress influencing sorghum development and production on the Vertisols of North Gonder. Waterlogging, along with traditional late weeding practices, affects and delays the growth and development of sorghum reducing the positive effects of fertilization. The experiment demonstrated that by offsetting those constraints, sound fertilizer management can strongly increase sorghum yield and profitability in the study area. The results showed that nitrogen fertilizer brought about a considerable increase in sorghum productivity and a significant decrease in the length of the maturity period. The adoption of the improved agronomic practices has allowed for a continuous crop growth, from the beginning of the rainy season thus avoiding terminal moisture stress. The mean length of the growing period of sorghum in the control plot in the watershed was 209 days. However, by applying fertilizers, timely weeding and draining excess water, the growing period of sorghum from planting to maturity was 169-172 days. The growing period was thus reduced by 37-40 days, which helped the crop to avoid terminal moisture deficit.

In this study the grain yield of sorghum increased from 1189 kg ha^{-1} to 4046 kg ha^{-1} with an increase of fertilizer rate from 0 kg ha^{-1} to 87 kg ha^{-1}. According to Yohana (2014) time of nitrogen application had significant effect on sorghum yield and yield related components. Split application of nitrogen gave higher grain yield. Split application of 41 kg ha^{-1}, 64 kg ha^{-1} and 87 kg ha^{-1} of nitrogen fertilizer, half at planting and half at knee height stage, gave 19%, 15% and 18% increase in sorghum grain yield over a single dose application, respectively. This result is in line with that of Mohammad et al. (2011) who reported significantly higher yield of wheat from two equal split applications of N with half dose at planting and half dose at knee height stage. Generally, split-application of N resulted in better performance than when the entire N was applied at once in rice (Tilahun et al. 2013).

Similarly, the application of nitrogen resulted in sharp increases in plant height, panicle length, thousand seed weight, effective number of tiller and stover yield in both seasons. This study showed that there was statistically significant difference in these sorghum yield related components by increasing nitrogen fertilizer from 0 kg ha^{-1} to 87 kg ha^{-1}. Increases in sorghum grain yield were mainly associated with improved panicle length, grain number per panicle, and grain weight. Application of 23, 41, 64 and 87 kg N ha^{-1} showed a yield increase of 40, 53, 62 and 69 % over the control (0 kg N ha^{-1}), respectively, in the watershed. Split application of 41 kg ha^{-1}, 64 kg ha^{-1} and 87 kg ha^{-1} of nitrogen fertilizer, half at planting and half at knee height stage, gave 19%, 15% and 18% increases in sorghum grain yield over a single dose application, respectively. This could be attributed to that application of full dose of fertilizer at one time for sorghum may lead to nitrogen loss since nitrogen is highly mobile and subjected to greater losses from the soil-plant system (Mengel and Kirkby 2001). In the Ethiopian Highland Vertisols due to water logging in rainy season nutrients can be leached. Hence draining the excess water from the plots and split nitrogen fertilizer application can reduce nutrient leaching. In high rainfall situations, leaching loss of nitrogen is unavoidable (Thomison et al. 2004). Excessive rainfall after planting often results in N loss through denitrification and leaching. Also, given the relatively high cost of fertilizer compared with produce, efficient use of N fertilizer is of both agro-economic and environmental importance (Nyamangara et al. 2003).

This result agrees with Buah and Mwinkara (2009) where they report that application of 40, 80 and 120 kg N ha^{-1} resulted in yield increases of 39, 43 and 45% over farmers' practice (0 kg N ha^{-1}), respectively. Mousavi et al. (2012) observed that application of N up to 150 kg ha^{-1} increased grain number, grain yield, and harvest index in sorghum. Hosein et al (2007) reported that longer period was observed in emerging and flowering time in the control plot (0 kg N ha^{-1}). Similarly, in Gumara-Maksegnit longer growing periods (209 days) were observed in the control plot without nitrogen fertilizer.

Since fertilizer is a costly input (US$ 0.78 per kg^{-1} for DAP, US$ 0.71 per kg^{-1} for TSP and US$ 0.65 per kg^{-1} Urea), its efficient management requires scientifically sound application so that the maximum return could be achieved. The economic analysis indicates that the efficiency of applied fertilizer can be increased by split applications. The economic analysis demonstrated that the application of 87 kg N ha^{-1} with the split application was economically profitable for sorghum production in the Gumara-Maksegnit watershed with a marginal rate of return (MRR) of 1207%. Buah and Mwinkara (2009) reported positive MRR of 281% for the change from zero nitrogen treatment to 40 kg N ha^{-1}. Applying 87 kg ha^{-1} nitrogen fertilizer with split application, along with 46 kg ha^{-1} of P_2O_5, gave the highest grain yield and income. Therefore, application of 87 kg ha^{-1} of nitrogen fertilizer with split application half at planting and half at knee height in combination with excess water drainage and timely weeding gave the highest grain yield.

6.5. Conclusions

Split nitrogen fertilizer applications can play an important role in a nutrient management strategy that is productive, profitable and environmentally responsible. Split nitrogen application can help growers enhance nutrient efficiency, increase yields and mitigate the loss of nutrients by leaching. In this research the effect of different levels of nitrogen fertilizer and its split application on yield and yield related parameters of sorghum was investigated for its profitability in Gumara-Maksegnit watershed. Applying 87 kg ha^{-1} nitrogen fertilizer with split application half at planting and half at knee height stage, along with 46 kg ha^{-1} of P_2O_5, gave the highest grain yield and income.

Due to waterlogging in the rainy season nutrients can be leached. Hence draining the excess water from the plots can reduce nutrient leaching. Therefore, application of 87 kg ha^{-1} of nitrogen fertilizer with split application half at planting and half at knee height in combination with excess water drainage and timely weeding gave the highest grain yield.

References

Aleminew A, Legas A, Misganaw M, Mamo M.2015. Yield Response of Sorghum to Timing of Urea Fertilizer Application in Eastern Amhara Region, Ethiopia. World Journal of Agricultural Sciences 11 (3): 144-150. DOI: 10.5829/idosi.wjas.2015.11.3.94284

Araki H, Hanada A, Hossain MA, Takahashi T. 2012. Waterlogging at jointing and/or after anthesis in wheat induces early leaf senescence and impairs grain filling. Field Crops Res. 137:27-36.

Buah SS, Mwinkara JS. 2009. Response of sorghum to nitrogen fertilizer and plant density in Guinea Savanna Zone. Agron. J. 8:124–130.

CIMMYT [International Maize and Wheat Improvement Centre]: 1988. From agronomic data to farmer recommendation: an economics of training manual; completely revised edition. Mexico: CIMMYT.

Demelash N, Bayu W, Tesfaye S, Zidat F, Sommer R. 2014. Current and residual effects of compost and inorganic fertilizer on wheat and soil chemical properties.Nutr Cycling Agroecosyst. 100:357–367.

Gezahegn A. 2001. Technological Innovation, Adoption and the Management of Vertisol Resources in the Highland Ethiopia.International Conference on African Development Archives.Paper 47.http://scholarworks.wmich.edu/africancenter_icad_archive/47

Gebremariam G, Assefa D. 2015. Nitrogen fertilization effects on grain yield (*Sorghum bicolor* L. Moench) yield and yield components and witchweed (*Striga hermonthica* (Del.) Benth) Infestation in Northern Ethiopia. Int J Agric Res. 10(1):14-23.

Hosein M, Mohammad RC, Hamid RM, Gholamreza SF, Abdolhadi HZ. 2007. Effect of method and time of nitrogen fertilizer application on growth, development and yield of grain sorghum. Asian J Plant Sci. 6:93-97.

Jackson ML. 1958.Soil chemical analysis. New Delhi: Prentice Hall of India.

Jutzi SC, Haque I, McIntire J, Stares JES. 1988. Management of Vertisols in sub-Saharan Africa. Proceedings of a conference held at ILCA, Addis Ababa, Ethiopia, 31 August-4 September 1987. ILCA, Addis Ababa

Landon, JR. 1991. Booker tropical soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 474pp.

Mafongoya PL, Bationo A, Kihara J, Waswa BS. 2006. Appropriate technologies to replenish soil fertility in southern Africa. Nutr Cycl Agroecosyst. 76:137-151.

Mengel K, Kirby EA. 2001.Principles of Plant Nutrition. 5thed. Dordretcht, the Netherlands: Kluwer Academic Publishers, 849 pp.

Mohammad T, Jamal Khan MD, Khan AD, Arif MD, Jan DD, Saeed MD, Zahir MD. 2011. Improving wheat productivity through source and timing of nitrogen fertilization. Journal Bot. 43(2):909 -911, Pakistan

Mousavi SGR, Seghatoleslami MJ, Arefi R. 2012. Effect of N fertilization and plant density on yield and yield components of grain sorghum under climatic conditions of Sistan, Iran J Plant Ecophysiol. 2:141–149.

Nyamangara J, Bergström LF, Piha MI, Giller KE. 2003. Fertilizer use efficiency and nitrate leaching in a tropical sandy soil. J Environ Qual. 32:599-606.

Olsen SR, Cole CV, Watanabe FS, Dean LA. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No 939:1–19

Promkhambut A, Younger A, Polthanee A, Akkasaeng C. 2010. Morphological and physiological responses of sorghum (*Sorghum bicolor* L. Moench) to waterlogging. Asian J Plant Sci. 9 (4): 83-193.

Sahilemedin S, Taye B. 2000. Procedure for soil and plant analysis. Addis Abeba: National Soil Research Center, Ethiopian Agricultural Research Organization.

SAS Institute Inc. 2004.SAS/STAT ® 9.1 User's Guide. Cary, NC: SAS Institute Inc.

Thomison PR, Geyer AB, Bishop BL, Young JR, Lentz E. 2004. Nitrogen fertility effects on grain yield, protein, and oil of corn hybrids with enhanced grain quality traits. Online. Crop Management doi:10.1094/CM-2004-1124-02-RS.

Tilahun T, Alemayehu A, Minale L, Zelalem T. 2013. Effects of nitrogen split application on productivity, nitrogen use efficiency and economic benefits of maize production in Ethiopia. Int J Agric Policy Res. 1 (4):109-115.

Tisdale SL, Nelson WL, Beaton JD, Havlin JL. 1993. Soil fertility and fertilizers, 5th edn. New York. Macmillan Publishing Company.

Wubie AA. 2015. Review on vertisol management for the improvement of crop productivity in Ethiopia. J Biol Agric Healthcare. 5(12):ISSN 2224-3208 (Paper): 2225-093X (Online)

Yohanna MK. 2014. Effect of time of nitrogen application on the performance of maize (*Zea mays* L.) varieties at Mubi, Northern Guinea Savanna of Nigeria.Am J Res Comm. 2(2):71-81.

7. Final conclusion

Soil resources are finite in extent, unequally distributed geographically, prone to degradation by land misuse and mismanagement, but essential to all terrestrial life and human wellbeing. Reducing soil erosion and fertility management are among the key factors for sustainability of soil ecosystem.

In this dissertation, Soil and Water Assessment Tool (SWAT) model has been used to predict the impacts of SWC interventions on runoff and soil loss for two adjacent watersheds in the highlands of Ethiopia. In addition, the effect of rate and timing of nitrogen fertilizer application on the possibility to shorten the maturity period and the productivity of sorghum has been assessed in the same watershed.

In this chapter 5 SWAT model was used to assess the impacts of SWC on runoff and erosion processes in the untreated (UW) and treated watersheds (TW).The results of the SWAT simulation study showed good model performance for daily runoff prediction at each watershed with acceptable R^2, NSE and PBIAS values. However, the model performance was poor in terms of predicting sediment loss with lower NSE values. Overall, the watershed modeling results indicated that soil and water conservation structures can reduce runoff and soil loss in the Gumara-Maksegnit watershed. The SWC structures reduced soil losses by 25-38% in the simulated results and the observed results in the TW as compared to the UW. The simulated and the observed results showed that soil erosion is still severe and above the soil loss Target value T (10 t ha^{-1} y^{-1}). Therefore, land management strategies and SWC structures should be improved to achieve more sustainable soil erosion protection for sustainable agriculture for food security in the area. Generally, this study found that SWAT can be used as a tool in other watersheds in the Ethiopian highlands to predict the impact of soil and water conservation structure (SWC) on runoff and soil erosion processes.

Chapter 6 presented the effect of different levels of nitrogen fertilizer and its split application on yield and yield related parameters of sorghum was investigated for its profitability in Gumara-Maksegnit watershed. Split nitrogen fertilizer applications have been found productive and profitable. Split nitrogen application can help growers enhance nutrient efficiency, increase yields and mitigate the loss of nutrients by leaching.

In general, these studies concluded that land management strategies and SWC structures should be improved to achieve more sustainable soil erosion protection for sustainable agriculture for food security in the area.

8. References

Bini C (2009) Soil: A precious natural resource. In Conservation of Natural Resources; Kudrow, N.J., Ed.; Nova Science Publishers: Hauppauge, NY, USA, 2009; pp. 1–48. 6.

Constable M, Belshaw D, (1986) The Ethiopian highlands reclamation study: major findings and recommendations. ONCCP (Office of the National Committee for Central Planning). Towards a food and nutrition strategy for Ethiopia: Proceedings of the national workshop on food strategies for Ethiopia, pp. 8–12.

Lamb D, Erskine P, Parrotta J(2005) Restoration of degraded tropical forest landscapes. Science 2005, 310, 1628–1632. 5.

Leon J, Osorio N. (2014) Role of Litter Turnover in Soil Quality in Tropical Degraded Lands of Colombia. Sci. World J. 2014, 13, doi:10.1155/2014/693981. 4.

Scherr SJ (2001) The future food security and economic consequences of soil degradation in the developing world. In Response to Land Degradation; Oxford Press: New Delhi, India, 2001; pp. 155–170.

Sertsu S, (2000) Degraded soils of Ethiopia and their management. In: Proc. 2nd Network Meeting FAO/ISCW expert consultation on management of degraded soils in Southern and East Africa, Sub regional Office for Southern and East Africa; Institute for Soil, Climate and Water, Pretoria Pretoria, pp. 18–22.

Tamene, L., Vlek, P.L., 2008. Soil erosion studies in northern Ethiopia. Land use and soil resources. Springer.

9. Index of tables

10. Index of figures

11. Curriculum Vitae

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2015 – Present: PhD Student in Environmental Engineering and Water Management, University of Natural Resources and Life Sciences, Vienna, Austria

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Project Coordination

2012–2013: Unlocking the potential of rain fed agriculture for improving Livelihood in Ethiopia. ICARDA (International Centre for Agriculture in Dry Areas)
2013–2015: Reducing Land Degradation and farmer's vulnerability to climate change, in Ethiopia. ICARDA (International Centre for Agriculture in Dry Areas)
2013 –2015: AGRA Project

Scholarships &Grants

June 2017: International Association of Geomorphologists, IAG Grants for 9th ICG Conference and young Geomorphologist Trainings, New Delhi, India.
May 2017: Marshall Plan Scholarship Award, Austria|Europe, University at Buffalo, New York, USA
March 2015: OeAD Scholarship, Vienna, Austria
August 2014: ICARDA (International Center for Agricultural Research in Dry Areas) Fellowship

12. List of Publications

12.1. Articles in Peer-Reviewed Journals

Nigus DM, Renschler CS, Holzmann H, Strohmeier S, Bayu W, Zucca C, Ziadat C, Klik A (2017). Prediction of soil and water conservation structure impacts on runoff and erosion processes using SWAT model in the Northern Ethiopian highlands. Journal of Soils and Sediments. DOI: 10.1007/s11368-017-1901-3

Nigus DM, Renschler CS, Flagler J, Bayu W, Klik A (2017). Assessing the impact of soil and water conservation structures on runoff and erosion processes through measurements and modeling. (***In revision at CATENA journal)***

Nigus Demelash Melaku, Wondimu Bayu, Feras Ziadat, Stefan Strohmeier, Claudio Zucca, Meron Lakew Tefera, Baye Ayalew & Andreas Klik (2017): Effect of nitrogen fertilizer rate and timing on sorghum productivity in Ethiopian highland Vertisols, Archives of Agronomy and Soil Science, DOI: 10.1080/03650340.2017.1362558

Hailu Kendie Addis, Stefan Strohmeier, Feras Ziadat, **Nigus Demelash Melaku,** Andreas Klik: Modeling streamflow and sediment using SWAT in Ethiopian Highlands. Int J Agric & Biol Eng, 2016; 9(5): 51─66. DOI: 10.3965/j.ijabe.20160905.2483

Nigus Demelash, Wondimu Bayu, Sitot Tesfaye, Feras Ziadat, Rolf Sommer 2014.Current and residual effects of compost and inorganic fertilizer on wheat and soil chemical properties. Journal of Nutrient Cycling in Agroecosystem. Nutr Cycl Agroecosyst (2014) 100:357–367.

Nigus Demelash, 2013. Deficit Irrigation Scheduling for Potato Production in North Gondar Zone, Ethiopia.African Journal of Agricultural Research. Vol. 8(11), pp. 1144-1154, 11 April, 2013.

Molla Fentie, **Nigus Demelash** and Tsedalu Jemberu, 2012.Participatory on farm performance evaluation of improved tef (Eragrostis tef L) varieties in East Belessa, North Gondar. International Research of Plant Science. Vol. 3(7) pp. 137-140, September, 2012.

12.2. Abstracts in Refereed Conference Proceedings

Nigus Demelash, Jared Flagler, Chris Renschler, Stefan Strohmeier, Hubert Holzmann, Ziadat Feras, Hailu Addis, Claudio Zucca, Wondimu Bayu, and Andreas Klik 2017. Comparison of SWAT and GeoWEPP model in predicting the impact of stone bunds on runoff and erosion processes in the Northern Ethiopian Highlands. EGU General Assembly 2017.Geophysical Research Abstracts.Vol. 19, EGU2017-6970-1, 2017.

E Obereder, A Klik, S Wakolbinger, G Guzmán, S Strohmeier, **Nigus Demelash**, J A Gómez 2016: Investigation of the Impact of Stone Bunds on Erosion and Deposition Processes Combining Conventional and Tracer Methodology in the Gumara Maksegnit Watershed, Northern Highlands of Ethiopia. AgroEnviroen 2016, Purdue University, West Lafayette, IN; 06/2016.

Nigus Demelash, Andreas Klik , 2016. Impact of cover crop on runoff, soil loss, soil chemical properties and yield of chickpea in North Gondar, Ethiopia. AgroEnviron 2016, Purdue University, Wets Lafayette, IN; 08/2016.

Andreas Klik, **Nigus Demelash**, 2016: Improving Sorghum Productivity in Waterlogged Vertisols in North Gondar, Ethiopia. AgroEnviron 2016, Purdue University, West Lafayette, IN; 06/2016.

Andreas Klik, Stefanie Wakolbinger, Eva Obereder, Stefan Strohmeier**, Nigus Demelash** 2016: Impacts of Stone Bunds on Soil Loss and Surface Runoff: A Case Study from Gumara Maksegnit Watershed, Northern Ethiopia. AgroEnviron 2016, Purdue University, Wets Lafayette, IN; 06/2016.

Renschler C. S., Klik, A., **Nigus Demelash**, and Omotayo, A.O. (2016). Quantifying impacts of climate and land use changes on soil and water management, community resilience and sustainable development in agricultural watersheds. Vulnerability of Agricultural Production Networks and Global Food Value Chains due to Natural Disasters. Conference Organized by the Technical University of Vienna, and the Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems Trade and Agriculture Directorate. Organization for Economic Co-operation and Development (OECD),Vienna, Austria.

Nigus Demelash, Andreas Klik, Hubert Holzmann, Feras Ziadat, Wondimu Bayu and Stefan Strohmeier, 2016. Impact of cover crop on runoff, soil loss, soil chemical properties and yield of chickpea in North Gondar, Ethiopia.EGU General Assembly2016; Vol.18, EGU2016-2464, 2016.

Stefan Strohmeier, Claudio Zucca, **Nigus Demelash** and Andreas Klik , 2015. Soil and water conservation effects of stone bunds at different scales – a case study from Gumara-Maksegnit watershed, Lake Tana Basin, Ethiopia. TROPILAKES2015.

Stefan Strohmeier, Jakob Rieder, Martin Kaltenleithner, **Nigus Demelash**, Gema Guzmán, Feras Ziadat, Andreas Klik 2015: Using magnetite tracer to evaluate anovel plot experimental design for the assessment of soil and water conservation impacts of stone bunds in Ethiopia. EGU General Assembly2015; 04/2015.

Jakob Rieder, Stefan Strohmeier, **Nigus Demelash**, Feras Ziadat and Andreas Klik 2014.Investigation of the impact of stone bunds on water erosion in northern Ethiopia.Geophysical Research Abstracts, Vol. 16, EGU2014-3885, 2014.EGU General Assembly 2014, Austria, Viena.

Martin Kaltenleithner, Stefan Strohmeier, **Nigus Demelash**, Feras Ziadat, and Andreas Klik 14. Investigation of the impact of stone bunds on soil water content - A case study in the northern Ethiopian Highland. Geophysical Research Abstracts, Vol. 16, EGU2014-3915, 2014.EGU General Assembly 2014, Austria, Viena.

Nigus Demelash, Sitote Tesfaye, Wondimu Bayu, 2012. Effect of the combined use of Compost and chemical fertilizer on the Yield of Wheat and Chemical Properties of Soil at Gummara-Maksegnit watershed. International Congress: Sustainable Livelihood in the Tropical Dry Lands, 2013.

Nigus Demelash, Molla, F., Yonas, W. 2010.Determination of timing and weeding frequency in direct seeded upland rice in North Gondar Zone.Proceeding of Annual Regional Conference on Completed ResearchActivities.Amhara Regional Agricultural Research Institute, Bahir Dar, Ethiopia.

12.3. Refereed Book Chapters

Nigus Demelash, Sitot Tesfaye, Wondimu Bayu, Rolf Sommer, Debra Turner 2015.Effect of Compost and Chemical Fertilizer on Wheat Production and Soil Properties. Mitigating Land Degradation and Improving Livelihoods: AnIntegrated Watershed Approach, Edited by Feras Ziadat (Editor) - Wondimu Bayu (Editor, 08/2015; Routledge.ISBN: ISBN13: 9781138785182

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