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Research Article

Erosion Results in the Degradation of a Soil's Productivity

Abolfazl Davari

Higher Educational Complex of Saravan
Corresponding author: abolfazl.davari23@gmail.com

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ABSTRACT

Several erosion processes are known, the most important being erosion by rain water (water erosion), wind (`wind erosion') and soil translocation by tillage (`tillage erosion'). All three damage the soil resource but only the first two additionally cause severe environmental problems because translocate soil leaves the arable area and enters neighboring ecosystems. Although water and wind erosion are different processes, they are governed by similar principles as far as land use is concerned. Soil surfaces destabilized by tillage and covered with little living or dead biomass are susceptible to erosive forces exerted by air or water. Erosion results in the degradation of a soil's productivity in a number of ways: it reduces the efficiency of plant nutrient use, damages seedlings, decreases plants' rooting depth, reduces the soil's water-holding capacity, decreases its permeability, increases runoff, and reduces its infiltration rate.

Key words: Erosion processes, Erosion Control, Sheet erosion, Gully erosion

INTRODUCTION

Soil erosion

Soil erosion is caused by the erosive forces of wind or water. In this publication, we focus our attention on concepts surrounding water-induced soil erosion. This type of erosion threatens our ability as humans to sustain our global population with food and fiber, and is closely linked to economic vitality, environmental quality, and human health concerns. Roughly 75 billion tons of fertile topsoil is lost worldwide from agricultural systems every year. In the United States, we lose an estimated 6.9 billion tons of soil each year (Pimentel, 2000). Losses at this scale are not sustainable and result in our increasing dependence on costly inputs such as fertilizers and soil amendments that we use in an attempt to make up for the beneficial qualities that were present in the lost topsoil (Pimentel, 2000). This article is review and the aim is erosion results in the degradation of a soil's productivity.

Erosion processes

Several erosion processes are known, the most important being erosion by owing water (water erosion), wind (`wind erosion') and soil translocation by tillage (`tillage erosion'). All three damage the soil resource but only the first two additionally cause severe environmental problems because translocate soil leaves the arable area and enters neighboring ecosystems. Although water and wind erosion are different processes, they are governed by similar principles as far as land use is concerned. Soil surfaces destabilized by tillage and covered with little living or dead biomass are susceptible to erosive forces exerted by air or water. Wind erosion is mainly a problem of coastal landscapes or large plains, while water erosion is of significance more widely. Furthermore, the amount of soil lost by water erosion far exceeds the amount lost by wind erosion in most cases (Heimlich & Bills, 1986). Hence, in the following analysis we will concentrate on water erosion, although to some extent our analysis may also hold true for wind erosion due to both processes having similar agricultural impact. Soil erosion is highly variable in time and space, which makes it difficult to base an assessment on short-term measurements only, for example over several years or on small plots. To overcome this problem many soil erosion models have been developed and are accepted tools for studying soil erosion (Nearing *et al.,* 1990). The Universal Soil Loss Equation (Renard *et al*., 1994; Wischmeier & Smith, 1978) is one of the oldest models, which is still frequently used. It has a large experimental background, has been adapted to many areas in the world and is still among the best tools for long-term assessment of soil erosion by water (Nearing, 1998). The model has been extensively customized over 20 years using data of about 1000 rainfall simulations and 500 plot years under natural rain summarized by Schwertmann *et al.* (1987).

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Soil's productivity

Erosion results in the degradation of a soil's productivity in a number of ways: it reduces the efficiency of plant nutrient use, damages seedlings, decreases plants' rooting depth, reduces the soil's water-holding capacity, decreases its permeability, increases runoff, and reduces its infiltration rate. The loss of nutrients alone resulting from soil erosion has an estimated cost to the United States of up to $20 billion a year (Troeh, Hobbs, and Donahue, 1991). The sediment deposited by erosive water as it slows can bury seedlings and cause the formation of surface crusts that impede seedling emergence, which will decrease the year's crop yields. The combined effects of soil degradation and poor plant growth often result in even greater erosion later on. All of these effects occur at or near the erosion site. Off-site impacts relate to the transport of sediment, nutrients, and agricultural chemicals and can be even more costly than on-site impacts. Severe economic and environmental costs are associated with the removal of sediment deposits from roads and from lakes and other surface water bodies. In the United States, more than 60 percent of water-eroded soils (about 2.4 billion tons of soil a year) end up in watercourses (Pimentel, 2000). This leads to the sedimentation of dams, disruption of aquatic ecosystems, and contamination of drinking water supplies.

Measurement of Surface Erosion

Erosion can be physically measured by erosion plots and erosion stakes or pins. Erosion plots are the most widely used method and consist of rectangular plots of specific size where the amount of eroded soil is collected down slope of the plot during and following natural or simulated rain events. The boundaries of the plots consist of walls of sheet metal, plastic, plywood, or concrete. A collection trough and container are installed on the downslope side to capture the runoff and sediment. The standard plot size is 6 feet by 72.6 feet (approximately 2 m by 22 m) that was used in the development of the Universal Soil Loss Equation (USLE). The USLE was developed by the United States Department of Agriculture, Agriculture Research Service in 1965 as a means to predict erosion over a broad set of surface conditions and climates (Brooks et al. 2013). For more detail on the USLE Equation, see Schoonover and Crim (2015, this issue), "An Introduction to Soil Concepts and the Role of Soils in Watershed Management." Erosion can also be measured from microplots 1 to 2 m2 in size, which are commonly used in research studies.

Types of soil erosion

In general, soil erosion is a three-step process. It begins with the detachment of soil particles, continues with the transport of those particles, and ends with the deposition of soil particles in a new location. Bare soils (soils that lack a cover of living or dead plant biomass) are highly susceptible to erosion, even on flat land. There are three main types of water- induced soil erosion: sheet, rill, and gully. The most common yet most overlooked form of soil loss is sheet erosion.

Sheet erosion

Sheet erosion is the uniform removal of a thin film of soil from the land surface without the development of any recognizable water channels (Figure 1). This type of erosion is barely perceptible, but the loss of a single millimetre of soil depth from an acre of land, which can be easily lost during a single irrigation or rain event, works out to a total loss of up to 6.1 tons of soil (Pimentel, 2000). Rill erosion is easier to recognize. It is the removal of soil through the cutting of multiple small water channels (Figure 1). Rills are small enough to be smoothed by normal tillage operations and will not form again in the same location. Together, sheet and rill erosion account for most soil erosion in agricultural land (Brady and Weil, 1999).

Fig. 1: Sheet erosion

Gully erosion

Gully erosion occurs in areas where water runoff is concentrated, and as a result cuts deep channels into the land surface. Gullies are incised channels that are larger than rills (Figure 2). You can remove small, ephemeral gullies by tilling, but they will form again in the same location on the landscape. Gullies actually represent less soil loss than sheet or rill erosion, but they pose added management concerns such as damage to machinery, barriers to livestock and equipment, and increased labor costs to repair eroded areas.

Fig. 2: Gully erosion

Development and transfer of soil conservation technologies

Soil is a vital resource for crop production (Troeh *et al*., 1999) and so its productive capacity should be maintained through use of appropriate technologies. Through research several land management technologies have been developed to combat effects of land degradation. These technologies include: use of legumes in crop rotation, mulching, terracing, biomass transfer, contour bunds, and agro-forestry (Keely, 2001). This study focuses on soil erosion control technologies because soil erosion is the major form of land degradation in Uganda. The technologies used by farmers around Mt. Elgon to control soil erosion are: contours, terraces, trenches, and agroforestry and Napier grass for stabilizing contours and terraces. These technologies are further elaborated on in the paragraphs that follow. Contours are constructed across the slopes on cultivated land to reduce the erosive power of runoff flowing through the cultivated land. They reduce soil erosion by intercepting runoff and reducing its speed. In a study done in the United States by Ripley *et al*. (1961), it was reported that contours can reduce soil erosion on gentle slopes by 25 to 80%. Trenches are dug along the contours to stop runoff, improve water infiltration and moisture storage capacity (Halmiton, 1997). Grass (such as Napier) and multipurpose trees can be planted along the contours to slow down runoff and catch sediments that have been eroded upslope. Planting vegetation along the contours and terraces stabilises the soil conservation structures, while contributing to improved productivity and biodiversity such as fodder, fuel wood, fruits and poles for building (Mati, 2005). On sloping lands, terracing is necessary for reducing overland flow rates thereby contributing to water and nutrient conservation. Some of the common terracing technologies used by farmers in Uganda are *fanya juu* and bench terraces. Bench terraces are commonly made on steep slopes and they are labour intensive. For this reason, bench terraces are rarely excavated directly but instead they are developed over time from *fanya juu* terraces (Thomas, 1997). *Fanya juu* terraces are made by digging a drainage channel and throwing the soil upslope to make a ridge. Just like in the case of contours, grass and multipurpose trees can be planted on the ridges to helpstabilise the ridges, prevent erosion and provide fodder and tree products (Thomas & Biamah, 1991).

Topographic influences on erosion

Slope steepness and length are critical factors controlling overland flow and erosion (Bryan and Poesen, 1989). As the slope increases, so does the probability that splashed soil will move downslope (Ellison, 1944). In a laboratory experiment, Quansah (1981) found that detachment rates increased slightly, and sediment transport capacity increased greatly on steeper slopes. Steeper slopes also enhance erosion via rill development due to increased shear velocities (Chaplot and LeBissonnais, 2000). On sloping land, there is usually net transport of soil downslope because displaced soil can travel further downhill than uphill due to gravity and slope angle. On a 10 percent slope, up to 75 percent of the splashed soil can move downhill (Ellison 1944). Huang *et al*. (1999) found that slopes < 5 percent resulted in net sediment deposition during simulated rain events in a laboratory experiment. On relatively flat surfaces, raindrop splash causes essentially no net soil loss because displaced particles are replaced by nearby soil particles that were displaced by raindrop impacts (Troeh *et al*., 1999). Long slopes generally result in high amounts of soil loss (Troeh *et al*., 1999; Brooks *et al*., 2013). However, the effects of slope length are complicated by the processes of seal development, rill development, and deposition. All of these processes have varying effects on infiltration and runoff and can occur simultaneously (Bryan and Poesen, 1989).

Erosion control

Erosion control can take many forms in many different activities. Mechanical, physical, and biological methods all can be used to reduce erosion and control sedimentation or locations of sediment deposition. Many of these methods are generally considered under the umbrella term of best management practices (BMPs), and they are used in agriculture, construction, forestry, mining, and other land uses in which erosion is a concern. BMPs are designed to reduce erosion at optimized cost, and they are based on physical principles that influence the energy of water and the erodibility of soil (Stuart and Edwards, 2006). Managers are well aware of the benefits of vegetation for soil stabilization, so revegetating disturbed sites is a fairly common BMP (Troeh *et al*., 1999; Kochenderfer, 1970). The revegetation process often includes soil amelioration (ripping compacted soils, fertilization, liming, etc.) and seeding followed by mulching, but also can be as simple as casting seed (Kochenderfer, 1970). Vegetative species selected for erosion control usually are prolific, fast growing plants with fibrous root systems that are able to rapidly cover bare soil and hold it in place (Troeh *et al*., 1999).

MATERIALS AND METHODS

This article is review and the aims of erosion results in the degradation of a soil's productivity. The experiment 1 was conducted by Barungi *et al*. (2013). This study was conducted in Eastern Uganda, in selected districts around the slopes of Mt. Elgon. The slopes of Mt. Elgon are characterized by high and well distributed rainfall (average of 1,200 mm/year), high altitude (700 to 2,800 metres above sea level) and cool temperatures, and relatively fertile volcanic soils. Kween and Bukwo districts were selected because, in these two districts, highlands cover about 37% of the total land area. Additionally, farmers in this area experience severe soil erosion associated with the steep rugged nature of the terrain and the problem is aggravated by heavy rains. A multi-stage (five stages) sampling procedure involving a combination of purposeful and random sampling procedures was used to draw a representative sample of farmers. The first step involved purposive selection of the two districts (Bukwo & Kween) where the problem of soil erosion is very severe and so the use of soil erosion control technologies is highly recommended. The next three steps involved random selection of 3 sub-counties per district, 2 parishes per sub-county and 2 villages per parish. Thus, in total 6 sub-counties, 12 parishes and 24 villages were selected for this study. The fifth (final) stage was the simple random sampling of farmers from the selected villages. To facilitate this final stage, lists of names of households in each selected village were obtained from the Local Council I Chairpersons. The names were assigned numbers and using a table of random numbers, 10 farmers from different households were selected from each selected village, hence, giving a total of 240 respondents. As alluded to in the previous section, primary data were collected from the 240 randomly selected farmers using a semi-structured questionnaire and through face-to-face interviews. The interviews were conducted during the months of March and April in 2011. A semi-structured questionnaire was used because according to Fowler (1998) it is an effective tool for minimizing bias and random error. Moreover, a semi-structured questionnaire allows the researcher to prompt and probe deeper into the given situation. In addition, the researcher can explain or rephrase the questions if respondents are unclear about the questions. The data was largely based on farmers' memory recall, because, in Uganda, keeping of records is not a regular practice among smallholder farmers. Data collected included: technologies adopted by farmers to control soil erosion, proportions of cultivated land that were under soil erosion control technologies, farmer specific characteristics like age and years of formal schooling, institutional factors such as access to credit and extension services, and farm characteristics such as size and location of cultivated land on the mountain slopes.

The experiment 2 was conducted by Kefi and Yoshino (2010). In this study, a method consists of a combination of environmental and economic model was applied in Boulabbouz watershed in Tunisia. The environmental approach is based on soil erosion model, remote sensing and GIS. The economical method is built using mathematic programming. Figure 3 shows the flowchart of the methodology. The watershed of the hillside dam Boulabbouz is located in Zaghouan between 36°14.404' to 36°16.9' N latitude and 10°10.833' to 10°10.868' E longitude (Figure 4).

Its area is about 1435 ha covered by rangeland and agricultural land suitable for cereal. The annual average rainfall is about 365 mm. The capacity of the hillside dam's reservoir is about 1 610 000 m^3. The water available is used for the irrigated perimeter. Its area is about 34 ha. The Revised Universal Soil Loss Equation "RUSLE" model aims at predicting soil loss from agricultural lands due to soil erosion by water. It is based on 5 factors related to rainfall, soil characteristics, topography, land use and land cover management. where A is the annual land loss (Ton/ha/year). R represents the rainfall erosivity factor (MJ.mm/ ha. Hr. year). K is the erodibility factor (Ton.ha.hr/ha.MJ.mm). C is the crop management factor. P is the supporting practices factor and LS is the slope length and slope inclination factor. C, P and LS are dimensionless. In this study, these 5 factors are represented on a raster with a cell resolution of 5 x 5 m and geo-referenced to the Universal Transverse Mercator (WGS 84 Zone 32 N).

They are computed using suitable datasets and appropriate software such as ERDAS imagine, Arcgis 9.2 and Arcview 3.2. In order to assess the impact of soil erosion, a soil loss constraint is added to the model. Therefore, the effect of soil erosion by water is evaluated by comparing the baseline scenario to two alternative scenarios where erosion is incorporated. The baseline model is the optimal situation using the current production plan of the farmers. Indeed, this scenario is to maximize the total net income of the watershed under several constraints related to irrigated and rain fed areas, labor, irrigation water, crop rotation, rangeland and olive trees areas. In addition, the area under rangeland and arboriculture should not change. Moreover, the first scenario consists of the valuation of soil erosion effect on-site. Indeed, a soil erosion constraint is added to the model. The total soil erosion and erosion effects by crops are obtained from the environmental approach. The second scenario is to evaluate the economic value of soil erosion on-site and off-site. Due to lack of data, the off-site effect of soil erosion is limited of the effects of reservoir sedimentation in particularly. To do so, the soil erosion constraint will be kept and it is supposed that 10 years of sedimentation will reduce the water available for irrigation.

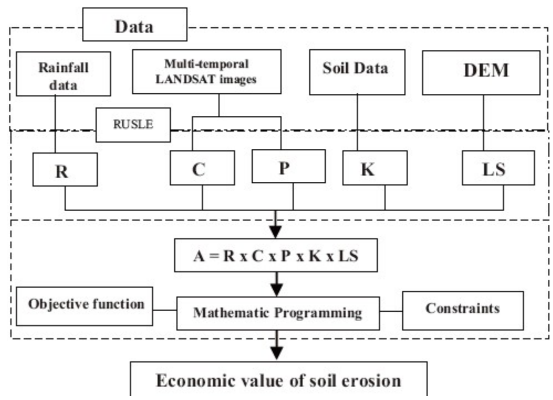

Fig. 3: Flowchart of the methodology

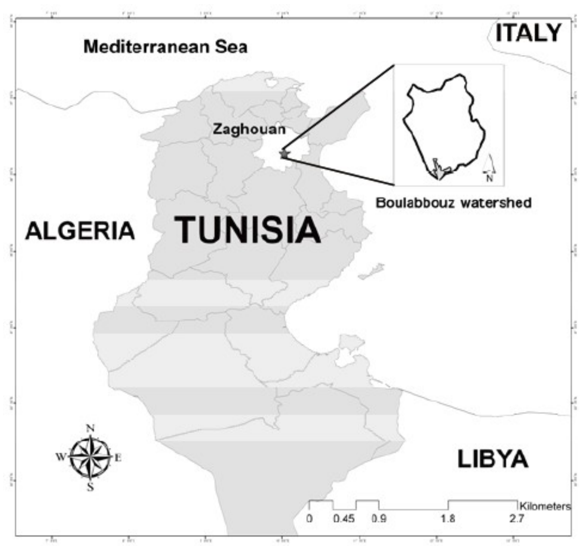

Fig. 4: Study area location

RESULTS AND DISCUSSION

In the experiment 1 was conducted by Barungi *et al.* (2013). Most farmers are taking measures to control soil erosion. They are combining soil erosion control technologies in several ways but some farmers are using only one type of technology. Contours and strips of Napier grass are the most commonly practiced technologies. The degree of use of soil erosion control technologies varies from farmer to farmer. However, on average, adopters are applying the technologies to about 70% of the cultivated land. Although the intensity of technology adoption is generally reasonably high, there are farmers who are using the technologies on smaller scales. From the foregoing, we conclude that more effort is needed to ensure that all farmers begin to use soil erosion control technologies and on full scale. In the context of this study, the number o economically active people in a household represents the size of the potential family agricultural labour force. Almost all (98%) farmers had ever attended school. However, close to 47% of the farmers only attained primary education. A remarkable proportion (38.5%) of farmers study up to secondary level. Only 12.6% of the farmers obtained tertiary education from vocational training institutes (9.6%) and Universities (3%). Level of education aside, the mean number of years of formal schooling completed was as low as 8.5 years (Barungi *et al*, 2013).

In terms of land ownership, the mean landholding was estimated at 1.1 hectares. However, most farmers (over 90%) owned less than 1.1 hectares – this is a clear manifestation of high inequality in land ownership. Some of the farmers who own very little land were forcefully evicted from Mt. Elgon National Park by the Uganda Wildlife Authority while restoring the park's colonial boundaries. Government has already resettled some households but others are yet to be resettled in areas outside the park (World Rainforest Movement's Bulletin No. 131, June 2008). Looking at the diversity of farm tools owned, it was noted that on average each household had three different types of farm tools (such as hoes, ploughs, oxen, and wheelbarrows). It should be noted though, that a considerable percentage (about 32%) of the farmers owned at most two types of tools. The mean annual household income was estimated at 1.38 million Uganda shillings but only 31.8% of the farmers had incomes exceeding this mean. This finding serves to emphasize the existence of income inequality not only in urban areas but also in rural areas as often reported by the Uganda Bureau of Statistics. Many (90%) respondents were doing farming as their primary (main) source of livelihood. On average, each farmer spent about 6 hours daily on farming activities (such as land preparation, planting, fertilizer application, weeding, and harvesting). Slightly over 23% reportedly spent more than 6 hours daily on farm related activities. More than half of the respondents (56%) had received extension services at least once during the past two years. The mean number of extension visits per farmer was extremely low (about 1 visit per year – yet there are two cropping seasons in a year). This means that delivery of extension services to farmers is not regular. Farmers reportedly received advice and training in several areas including: sustainable land management, agro-enterprise diversification, crop and livestock management, group formation and planning, among others. Many farmers (about 42%) accessed extension services from the National Agricultural Advisory Services (NAADS) program and other Government agricultural officers. The second most important source of extension services was farmer groups/associations – accessed by 24% of the farmers. Some farmers (15%) accessed extension services from Non-Government Organizations' such as Kapchorwa District Landcare Chapter (KADLACC). Most (about 91%) farmers have adopted soil erosion control technologies. However, some adopters (27.5%) were using just one type of technology on their farms - either contours or terraces or trenches, or Napier grass or trees. Usually on most cultivated lands, use of one type of technology is necessary but not sufficient to control soil erosion. Therefore, farmers are advised to combine several technologies. Indeed, there are farmers who were combining a set of technologies. The mean number of

Table 1: Description and summary statistics of variables used in econometric analysis (Barungi et al, 2013)

Variable name	Variable description	Measure	Mean	Std
Soil fertility of the farmland as perceived by the farmer				
Not_fertile	Soils cultivated are not fertile	1 = Yes, 0 = No	0.11	0.32
Moderate_fertility.	Soils cultivated are moderately fertile	1 = Yes, 0 = No	0.65	0.48
Fertile	Soils cultivated are fertile	1 = Yes, 0 = No	0.24	0.43
Distance to markets		1 = Yes, 0 = No		
Short_mktdist	Distance from farmer's home to the nearest market is≤ 1km	1 = Yes, 0 = No	0.49	0.5
Medium_mktdist Distance from farmer's home to the nearest market is	Distance from farmer's home to the nearest market isover 1 km but does not exceed 3 km	1 = Yes, 0 = No	0.19	0.39
Long_mktdist	Distance from farmer's home to the nearest market isbeyond 3 km radius	1 = Yes, 0 = No	0.33	0.47

Table 2: Relative importance of factors that affect farmers' decisions regarding adoption of soil erosion control technologies (Barungi et al, 2013).

	Marginal Effects and Robust Standard Errors (in parenthesis)				
	Contours trees	Terraces	Trenches	Napier	grass
Years of formal schooling	0.002 (0.011)	0.005 (0.010)	-0.010 (0.011)	0.007 (0.011)	0.012 (0.012)
ln Age (years)	-0.023 (0.113)	-0.037 (0.102)	0.190 (0.109)*	0.106 (0.118)	0.108 (0.122)
ln Number of adults in a household	-0.030 (0.079)	-0.062 (0.071)	-0.094 (0.080)	-0.102 (0.084)	0.131 (0.089)
sqrt Number of different types of farm tools owned	0.144 (0.080)*	0.056	0.262 (0.093)***	0.176 (0.074)**	0.418 (0.099)***
ln Number of daily farming hours	-0.058 (0.097)	0.010 (0.082)	-0.103 (0.094)	-0.207 (0.101)**	-0.142 (0.097)
ln Size (hectares) of land owned	0.022 (0.043)	0.012 (0.040)	-0.004 (0.041)	0.082 (0.043)*	-0.025 (0.047)
Sex (1= Male, 0 = Female)	-0.014	0.091) 0.264	-0.228 (0.054)***	-0.095 (0.095)**	-0.219 (0.089)

Note: ***, ** and * represent statistical significance at 1%, 5% and 10% levels, respectively.

Table 3: Satellite image use (kefi and yoshino, 2010)

N°	Path / Row	Sensor	Acquisition Data
1	191 / 35	Landsat 5 TM	31/12/2006
2	191 / 35	Landsat 5 TM	22/04/2007
3	191 / 35	Landsat 5 TM	25/06/2007

Table 4: Land occupation distribution (kefi and yoshino, 2010)

Class	Land occupation	C factor
1	Rangeland	0.21
2	Olive trees	0.33
3	Cereals	0.30
4	Market garden	0.42
5	Bare land	1

technologies used by each adopter was 2 technologies. Close to 73% of adopters were combining 2 or more technologies. There are over 20 ways in which farmers were combining and applying soil erosion control technologies but the five commonest ways were: contours + Napier grass (10.6% adopters); contour + terraces + trenches + Napier grass + trees (7% adopters); contours + Napier grass + trenches (6.4 % adopters); contours + Napier grass + trees (6.4% adopters); and contour + trenches + Napier + trees (5.5% adopters). Generally, contours were the most adopted (57.3%) soil erosion control structures. Over 47% and 43% of farmers had planted Napier grass and were practicing agroforestry, respectively.

Digging trenches was the second least adopted technology and was practiced by about 37% of the farmers. Terraces were the least adopted structures and only 30% of the farmers had terraced farmlands (Barungi *et al.*, 2013). During the survey, farmers reported that making terraces and digging trenches is labour intensive, and this makes the two technologies less attractive. The model estimated to identify the determinants of adoption of terraces was statistically significant at 1%, an indication that it is a good fit. Results revealed that adoption of terraces is positively and significantly influenced by: sex of the farmer; downslope and mid-slope locations of cultivated land on the mountain slopes; and the perception that cultivated soils are not fertile (Table 2). The estimates of marginal effects indicate that the probability that a male farmer will adopt terraces is 26.4% higher than that of a female farmer (Barungi *et al.*, 2013).. The probability of adopting terraces is about 18% higher for farmers whose farmlands are downslope than for those whose farms are upslope. Similarly, the probability of adopting terraces is about 14% higher for farmers whose farmlands are mid-slope than for those whose farms are upslope. The probability of adopting terraces is 24.5% higher for farmers with a perception that their soils are not fertile than for those who perceive their soils as fertile. We would expect that farmlands upslope are more prone to soil erosion and therefore use of erosion control technologies is paramount. Similarly, since land is a scare resource, farmers with soils that are not fertile definitely need to take measures to rejuvenate the soil fertility and maintain it thereafter. Thus, we note a need for targeted extension advice especially to farmers doing farming upslope and those with soils that are already degraded (Barungi *et al.*, 2013).

In the experiment 2 was conducted by kefi and yoshino (2010). The results showed that in order to obtain the economic value of soil erosion by water, the annual soil loss of the watershed using RUSLE model is estimated. This value is then incorporated in the mathematic programming as a constraint. RUSLE erosion model is composed of 5 factors and the finding of each one is presented below. The R factor is considered as the most important factor for soil erosion by water. In this work, the average of R factor is about 396.77 MJ.mm/ ha. hr. year which can be considered as a low value of erosivity. The mean value of K factor is 0.032 Ton.ha.hr/ha.MJ.mm which is recognized as a moderate soil erodibility (Kefi and Yoshino, 2010).

C factor depends on the land use. Moreover, the supervised classification indicated that the watershed is covered especially by rangeland, dry farming land such cereal, olive tree and irrigated crops such as melon and watermelon in summer and bean in winter. The finding is shown in Table 3. Furthermore, the relationship between the C factor and the TSAVI is obtained using a statistical regression. This regression is based on the correlation of the C factor value of each land use and the mean value of the TSAVI's pixels. This vegetation index is acquired by estimating the soil line.

Table 4 shows the characteristics of the soil line. In this study, three satellite images with different periods of phenology cycle of the crops are used. Indeed, the image of December shows the beginning of the growing cycle of cereals and winter irrigated crops (Kefi and Yoshino, 2010). April image represents the growing period of cereal and the harvest season of winter crops and beginning of cycle of summer crops. June image indicates the harvest period of cereal and growing period of summer crops. Additionally, the best-fit regression equation of the relationship between C factor and TSAVI is an exponential equation which can be written as follows. Where and are respectively 1.02 and 14.25 Furthermore, the result of this relation is shown in table 4. The results show that LS value is high in mountain area. Indeed, about 6 % of the watershed has an LS factor more than 5 which indicated high slope steepness and consequently, a high vulnerability to erosion. However, about 39% of the watershed particularly the area close to the reservoir of the hill dams has an LS factor lower than 1. It represents the flat land of the watershed (Kefi and Yoshino, 2010).

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