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Survey of Rill Erosion Characteristics of Small-scale Farmers' Crop Fields in the Northern Part of Taraba State, Nigeria

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ABSTRACT: *Soil erosion is of great concern in the agricultural fields in Nigeria. It threatened agricultural lands and constrained farmers from achieving an acceptable level of food security. Erosion assumes disastrous proportions with increased intensification of agricultural activities on erosion prone areas such as hillslopes and flooded plains. This paper reports results of field-scale erosion assessment that employed a survey methodology for rills, in 10 agricultural fields, located on two contrasting topographies with similar crop types. The desire was to gain an understanding of the farmer's reasons for cultivating hillslopes, while, flatland areas exist in the study region. The average rill erosion magnitudes were 1.158 t/ha/yr, in the hillslopes, and 0.643 t/ha/yr, in the flatlands. Assuming that interrill erosion contributes 30%, actual soil losses was estimated at 1.501 t/ha/yr (3.37 Mg ha^{-1} per year) in hillslope and 0.836 t/ha/yr (1.87 Mg ha^{-1} per year) on the flatland. These estimates were within the range of soil loss by water erosion in agricultural fields, regarded as optimum for soil formation in the ecological region. This implies that rill-erosion, is a threat to agricultural production in both sites and, therefore, the farmer's reasons for cultivating hillslope while flatland exist in the study region.*

Keywords: *Land use site, Nigeria, Rill erosion, Small-scale farmers.*

INTRODUCTION

Soil erosion by water is recognized to be an important global environmental and economic problems, causing loss of valuable soil qualities and consequent decline in agricultural productivity [1-7]. Although, accelerated soil erosion scenarios is seen all over the world irrespective of geographical, climatic, ecological, and political regions, and constituting a serious threat to the long-term viability of agricultural productivity, nowhere is this problem more severe than in the developing countries particularly Nigeria, where the resilience ability of the soil threatened by soil erosion with potentially very significant adverse effects on food production [1, 8-10]. Meanwhile, it predominantly poor-resource farming population cannot afford optimum replacement of loss soils and qualities [11].

The magnitude of accelerated soil erosion by water problem in Nigeria is alarming and constituting a grave threat to the economic development of the country that is primarily agrarian [8, 12]. Soil loss due to water erosion is estimated at 1353 million Mg per year, with over 70% coming from cultivated fields which account for 32% of the country's total land area [13-16]. The soil loss rates in the cultivated areas are estimated to ranges from 65 to 200 t/ha/year, which is over 100 times faster than the replacement rate of topsoil [17, 18] With much of this rate of soil losses coming from the slopes of the highlands, with fragile soil resource base, where agriculture is practiced [1, 6]. The mean annual loss of crop production capacity through erosion was estimated to be 25 million tones [19].

Of the forms of soil erosion by water in Nigeria, rill erosion remains an important mechanism of soil loss under agricultural land uses, because, in addition to being and important erosion feature in itself, it serve the purpose of transporting the selectively removed fine material and organic matter that are very important determinants of land productivity supplied by the interrill erosion [20-22].

In the study region, as elsewhere in the humid tropical, the impact of rill erosion problems on

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agricultural lands is observable with over 75% of the cropped land areas particularly on the hillslope threatened by serious rill erosion problems, and much of that have been abandoned for agricultural activities [17, 23-25]. However, unlike in most areas in the humid tropical region, where the productivity of land is safeguarded to feed the ever-growing world population, just at a time when agricultural efforts are focusing on increasing crop yields, through sustainable soil management. In the study region, increased farming activities on hill slope areas often described as soil erosion hotspot zones have raised in the later years.

This was, despite large cultivatable hectares of land on the flatland. Such increase conversion and intensification of agriculture on the hillslopes areas has made it vulnerable to rill erosion, and the problems related to the loss of large farm lands to rill/gullies, in addition to valuable soil qualities, with its consequent negative effects on productivity, food security and wellbeing of rural farmers have increased in recent years [19, 26]. This increased conversion and intensification of agricultural activities on the hill slopes, disregarding the flat land provided by nature, makes research on them pressing.

In addition, virtually, all existing information and records in the literature including those of [27-29], dealt with soil loss rates due to rill erosion mostly from off-farm sites, while, the severity and magnitude of soil erosion from on-farm were extrapolated from the plot level investigations [30-33]. Very little or no studies focused attention on rill erosion survey of soil loss from cultivated fields and particularly under two contrasting landscape.

Moreover the importance of soil erosion assessment that employed a survey methodology for rills cannot be over-emphasized. It among other things enhances farmer's proper understanding of the processes and magnitude of soil loss from cultivated farms and the bases for longtime practical conservation strategies [34-36],[37, 38]. Rill survey, is also, presently accepted as a good alternative approach to soil erosion investigation, because the measurement of erosion feature volumes is done quickly with satisfactory precision, low cost, and eases, and can be apply to practical conditions under actual on-farm situations [39-42].

In addition, though, rill survey is regarded as a semi-quantitative and qualitative method, for assessing the extent of erosion damage under field conditions, and its results often assumed to be within 15% accurate based on careful measurements [36, 43-46]. It does notinvolved the use of expensive instrumentations, long lead times and simple or sophisticated modeling. [39, 42, 47]. The overall goal of this study was to assess and compare the magnitude of soil erosion at the scale of cultivated farms located on two contrasting topographies (hill slope and flatland), under similar crop types, by using survey methodology for rills. The desire was to gain a better understanding of farmer's reasons for cultivating hill slopes, while, flat land areas exist in the study region. This desire is connected with the agricultural, residential, industrial and engineering support potential of the study area.

MATERIAL AND METHODS

2.1. The Study Region

This article is based on a survey undertaken on two contrasting landscapes; the highland and flatlands in northern Taraba State, North- Eastern Nigeria, (6°30[1] to 9°36[1] N and 9°10[1] to 11°50[1] E) (Fig. 1). The highlands constituted about 30% of the region's land mass, with an elevation fluctuating from an average of 1,800-2,400 meters above sea level [48, 49]. The landscape is characterized by undulating and a rugged topography with steep slopes, while, the lowland made-up the 70% of the region's land mass. It is gentle and flat, occasionally punctuated with hills and rock outcroppings. The mean annual temperature varies between 24°C to 32°C in the highland and lowland respectively. The relative humidity was (65-90%), earth temperature at 0-20cm soil depth (25-30°C), evaporation rate (2-5 cm/day) and sunshine hours (6-7) per day in both sites.

Both sites were characterized by a humid tropical climatic condition [48, 49]. Mean annual precipitation is about 1050mm and 1300mm in the low and highland regions respectively. The differences in elevation could be instrumental to the level of variation in the amount of precipitation received. Accordingly, although no measurements were taken, it was observed in the field that rainfall was more intense in the highland areas than on the lowland areas. In terms of temporal distribution, which has important implications for soil erosion [13, 17, 50], rainfall is unimodal at both sites, with the wet season

Table 1
Mean Soil properties (0-20cm) of the two contrasting sites of the study region

Soil properties	*Hill slope*	*Flatland*
% sand	64.1	61.8
% silt	20.6	19.6
% clay	15.3	19.1
Bulk density (g/cm^3)	1.33	0.9
Soil organic matter (gkg^{-1})	8.87	10.52

extending from April-October, and a peak in July and August. The time of the start of the rains is the end of the dry season, over which all cultivated fields stayed as communal grazing grounds, and the soils exposed to the vigorous sun. This means that the soil is barely covered by the beginning of the rainy season, making it highly vulnerable to water erosion.

In both sites, soil types are predominantly ferruginous tropical soils and lithosols, which developed on crystalline acid rocks and sandy parent materials [8, 14, 51]. Characterizes by a sandy surface horizon, with clay subsoil in the lowland and clay loam in the highland areas (Table 1). The soils are naturally fertile for agricultural productivity, and susceptible to erosion especially on marginal areas where agriculture is the practice and has low water-holding capacity [8, 11, 52].

Farming is the primary traditional occupation of the people of the area [53]. The agricultural system

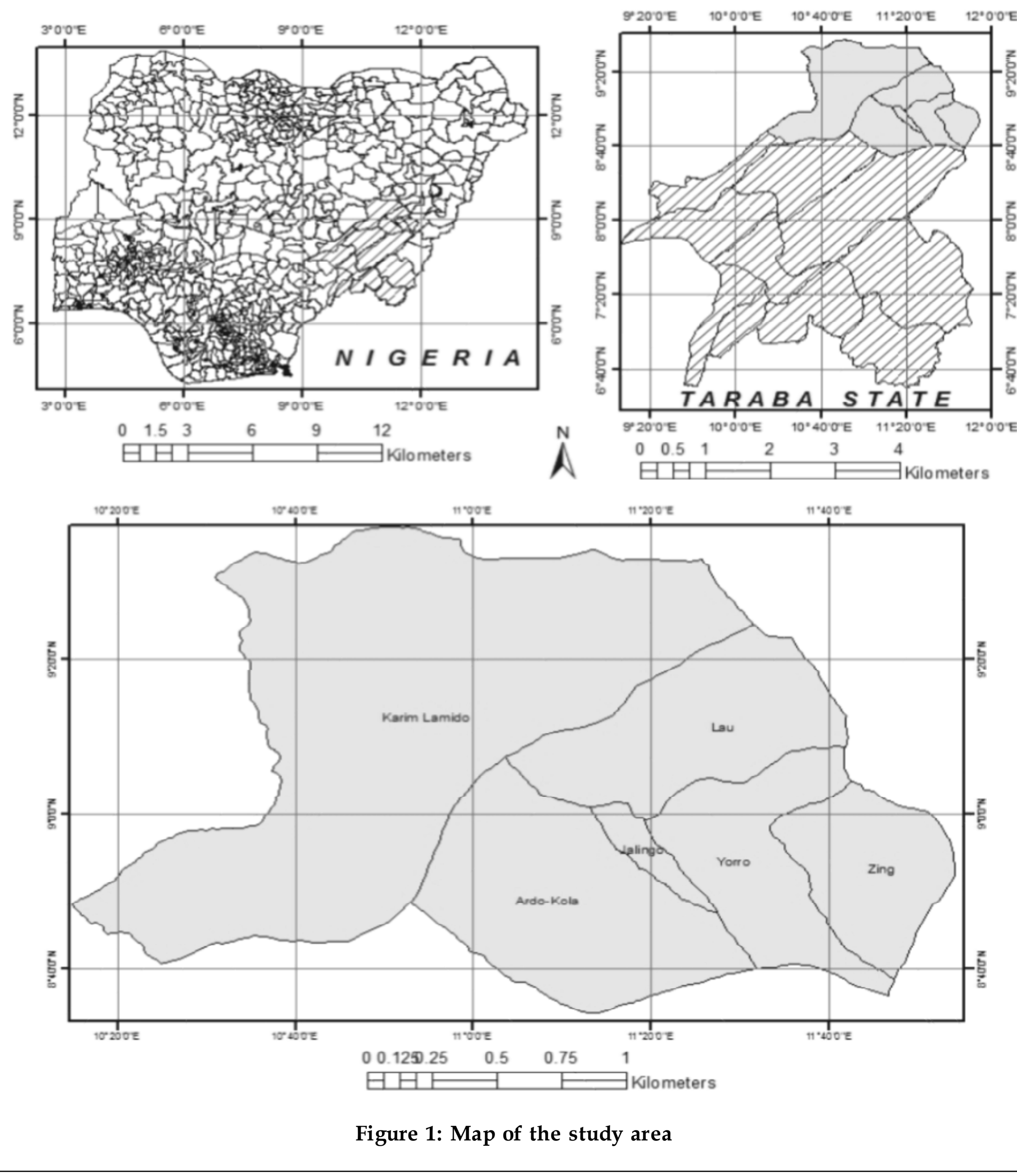

Figure 1: Map of the study area

is typically one of subsistence: where mixed crop and livestock farming system is the practice. Farm sizes vary from place to place reflecting population density, accessibility to the farm and personal preferences of the occupants to each other [53]. Yam and guinea corn are the principal crops being cultivated by almost every farm family in both sites. Other crops include millet, rice, cassava, potatoes, groundnut, beans, and vegetables. Plowing of the fields commenced with first rains, varying in frequency with sites and crop types. In highland areas, plowing of field's starts before the first rains and repeated before sowing. This is because farmers believe that it controls weeds, and crop yield will be better. The yam fields in the highland areas were plowed three to four times while, on the contrary, in the lowland yam fields were plowed only once or twice, and for other crops, the fields were plowed only once in both sites. Though, the plowing created a very rough surface, which provided a large storage space for the rainwater, which protect the soil from erosion [8], as the amount of rain increases, the roughness decreases over time, mainly due to raindrop and surface runoff impacts, which triggers erosion. The farming operations are generally labour–intensive, and largely a reflection of traditional methods using chore-strengthening primitive tools, such as hoes, cutlasses, axes, and matches, which have been passed from generation to generation [53]. Cattle, sheep, goats, and poultry, are among the common types of livestock raised in the area. The only soil conservation practices applied by the farmers in both sites were traditional trenches known locally as. "*Lambatu*" that were meant for safe disposal of surface runoff. The differences between the two sites in terms of land use and management practices were negligible.

Method

2.2.1. Field survey

Northern part of Taraba state comprises of six Local government areas and 62 districts with a range of between 21-47 major villages and approximately 155-348 farm families in each district and villages. The study region has an estimated total area of 16,719 km^2, with over 55% classified as suitable for agricultural activities, and a population of 778,131, inhabitants in 2013, with an annual growth rate of 3.1% (NPC, 2014).

In other to attain the objectives of this study, a reconnaissance survey of the study region was undertaken to identify the major topographical, agricultural land uses sites, and farming systems that are dominant in the area. During this stage, many comparable agricultural land use sites (hill slope and flatland) areas were identified under a similar geographical setting with respect to climate, soil and crop types.

A stratified random sampling technique was employed at the village levels, and a village was purposively selected for soil erosion measurement. The most important consideration, in choosing the village, were: The severity of rill erosion problem; accessibility; the needs to have two comparable slopes and flatland farms representative of the study area, and the selection considered land use types, rather than soil types as the objective was to compare the magnitude of soils with respect to differences in the land use sites. From the village selected, two comparable sites (highland and lowland) were randomly selected and subsequently 10 representative farm plots.

Rill surveying procedure

Ten representative farm plots, five each from the hill slope and flatland farm areas were selected randomly. Slope angles ranged from 5% to 22% and 0% to 4% on the hill slope and flatland farm plot areas respectively. Farm plots under the hillslopes were categorized into three slope positions: upper slope, middle slope, and down slope farms. Base on the relative slope positions, 3 farms was selected from the mid-slope and one each from the upper and downslope positions. More mid-slope farms were selected because they represented the slope angle of much of the cultivated farms in the study region. While, on the flatland the survey farms were regarded as having uni-model slope area.

The study was conducted between the months of July to September, 2014, when the amount of rainfall triggering substantial soil loss in the study region was recorded. Each farmland was recurrently visited immediately after the rainfall storms to measure the fit rill on the farms. However, due to time and resources constraints, only the rills length, width, and depth were carefully measured, despite the significant impacts of channel size [54], and shape of rills on measurement accuracy [45, 55-57].

To allow for the determination of different magnitudes and rill volumes, which in turned, allow for estimation of soil loss rates, rills density, and area of actual damaged by the rill with an acceptable margin of error, the length of fit rills were measured

Table 2
The sum of rill length, farm size, area damage, volume of soil lost from the rill (m^3), volume lost per m^2 (Soil loss m^3/m^2) and soil loss (t/ha) at the two site of the study region

Farm position *Hill slope*	*Sum of rill length*	*Farm Size (ha)*	*Area of actual damage (m^2)*	*Damage area out of total area %*	*Volume of soil lost from the rill (m^3)*	*Volume lost per m^2 Soil loss (t/ha)*	*Soil loss (m^3/m^2)*
1.	594	0.6	2.24	0.04	1327.29	0.221	0.294
2.	424	0.5	1.18	0.02	498.62	0.100	0.133
3.	292	0.5	1.00	0.02	293.29	0.059	0.078
4.	645	0.8	4.68	0.06	3015.38	0.377	0.501
5.	445	0.5	1.28	0.03	568.89	0.114	0.151
Sum	2,400	2.9	10.37	0.17	5703.47	0.870	1.158
Flatland							
1.	401	1	3.09	0.03	1238.61	0.124	0.112
2.	367	0.9	2.55	0.03	936.58	0.104	0.094
3.	559	1.5	5.07	0.03	2833.96	0.189	0.170
4.	377	0.7	2.04	0.03	767.50	0.110	0.099
5.	569	1.5	4.95	0.03	2817.57	0.188	0.169
Sum	2,273	5.6	17.70	0.15	8594.23	0.714	0.643

from their initial point of emergence up to the point where the eroded soils were deposited. While, the lengths of rills that come laterally and merge with a central rill, were measured from their starting point to their point of convergence with the main rill. To provide a better estimate of the rill mean width, the width of rills were measured at three points along a rill length, depending on the depth, measurement was taken at two or three depths at a point and several points along the length.

From each farm in both sites, maximum fit rills, both in number and dimensions, was attained to by 30th September, 2014, after which no significant changes was recorded in the rill dimensions, despite the progressive soil losses when rainfall occurs. Thus, only the maximum values recorded were analysis as representative of the total soil loss by rill erosion. During the investigation, in-farm observations of the presence of surface runoff from areas in the upslope direction entering into the fields, rill networks within farms, their patterns and incidence of deposition were made. Similarly, the percentage of the crop canopy coverage was estimated whenever each rill measurement was undertaken. However, measurement of damages caused by the siltation of eroded materials were not made, as well as on-site rainfall measurements, because the best approach to erosion measurement due to rills are estimation of soil losses, and they exclude soil loss by the inter-rill erosion processes [38, 39, 45, 57].

Data Analysis

The quantitative data analysis involved the calculation of eroded soil volumes, areas of actual damage and rill densities, from the measured length, width, and depth dimensions of the rills. The volume of soil lost from a rill (m^3) was calculated from the product of depth (m), width (m) and length (m). Prior to this, the average width and depth of rill were converted to meters by multiplying with 0.01. The calculated volume is equivalent to the amount of soil loss due to rill formation. From each of the farm plots, the total volume of soil loss (m^3) was converted to a volume per square meter of farms, by dividing the volume of soil lost (m^3) by the square meter of farm area (m^2).

The calculated value is equivalent to the soil loss in (m^3/m^2). The volume of eroded soil was obtained by multiplying the calculated volume of soil loss in (m^3/m^2) by the measured bulk density and expressed in terms of annual soil loss (t/ha/yr).

The area of actual damage per a unit hectare (total area surface covered by rills themselves) was obtained from the product of width and length dimensions of each homogenous rill segment. While, the rill density was calculated by dividing the total rill lengths (obtain by summing up the measured length values of all rills) by the total area of the survey farms and expressed in per unit hectare of land. The study did not employ advanced statistical techniques as did Bewket and Sterk [39], because it was based on survey data, which cannot be taken as accurate measurements of soil loss. [58], also, suggested that advanced statistical methods should not be employed to analyze rill survey data. The qualitative data generated through the in-field observations were used to substantiate and augment the findings from the quantitative rill survey data.

RESULT AND DISCUSSION

The Magnitudes of Rill Erosion

Table 2 shows the sum of rill length, farm size, area damage, volume of soil lost from the rill (m^3), volume lost per m^2 (Soil loss m^3/m^2) and soil loss (t/ha) at the two site of the study region. The total number of the rill was 2,400 in the hill slope farm plots and 2,273 in the flatland farm plots. Rills were formed in all the ten surveyed farms in both sites. The total lengths of all rills that represented rill densities are larger in the hill slope farms with 0.08 than in the flatland farms with 0.04. However, because of the exclusion of inter-rill erosion, the measured rill erosion rates would be an underestimated of the actual rate of soil loss. Govers [36], asserted that, the contribution of inter-rill erosion can be more than 30% of the total soil loss in fields where rills are present. Assuming that the measured rill erosion rates were underestimated by 30%, then the actual soil loss rates were 1.501 t/ha (equivalent to 3.37 Mg ha^{-1} per year) in hillslope and 0.836 t/ha (equivalent to 1.87 Mg ha^{-1} per year) on the flatland.

A significant little difference between the two sites by the number of rills and the volumes of soil lost per year is recorded as in Table 2. However, such differences could probably be related to differences in the biophysical factors such as rainfall characteristics, slopes of the surveyed fields and soil properties. During the field measurements, it was observed that there were no significant differences in land use and management practices between the two sites to provide any explanations. Therefore, this is a reason for farmer's choice of erosion prone areas while flatland remains. Similarly, the area of actual damage, the surface area covered by the rill themselves, was more or less equal at the two sites 0.11 and 0.15% of the total farm areas surveyed (Table 2).

Though, the loss rates are higher in the hill slope than flatland farms, compared to the average soil loss rates estimated to occur from cultivated fields in the country (42Mg ha^{-1} per year) [8, 17]. The estimated soil loss rates in both sites were much lower, yet, within the range of soil loss due to water erosion under cultivated farms reported to exceed the rate of soil formation per year in the region, but marginally [8, 17]. This, therefore, is one of the farmer's reasons for cultivating hill slope areas while flatland exists.

This analysis showed the direct impact of rill erosion on productivity of the cultivated fields via reduction of the total areas. However, the impact of rill erosion is much more than just a reduction in the area of the productive land [39]. Rill erosion is a result of surface run-off and associated sheet wash, which is a process that selectively removes fine material and organic matter that are very important determinants of land productivity.

Rill Classification

Table 3 shows soil erosion is caused by four categories of rills in the ten farms at the two contrasting topographies. Classification of the rill by taking into accounts both depth and a width dimension simultaneously was not possible because widths varied widely. Hence, only depth was used to classify the rills into sizes. Accordingly, four classes of rill were identified; small, (or shallow) (≤ 15 cm), medium (16-30 cm), large (31-45) and very large (≥ 46 cm).

Table 3
The categories of rills in the ten farms at the two contrasting topographies

Sizes of rill	*Hill slope farms*		*Flatland farms*	
	No. of rills	*Total soil loss (m^3)*	*No. of rills*	*Total soil loss (m^3)*
Small	1	293.29	2	3585.07
Medium	3	4841.80	3	5009.16
Large	1	568.89	–	–
Very large	–	–	–	–
Total	5	5703.98	5	8594.23

*Small (≤ = 15), medium (16-30cm), large (31-45cm) and very large (≥ 46 cm)

Following this classification, the hillslope farms fall into the small, medium and large size categories, with the medium accounting for the lion's share while, in the flatland, the total rills were in the small and medium size classes, with the medium-sized rills equally contributing the largest share to the total soil loss, matching the number of rills. The contribution of the medium rills to the total soil loss and the total area of actual damage in both sites was higher proportionate to their contribution to the total number of the rills [58].

However, the effect of the majority of the rills been medium is that sedimentation feature that indicates the redistribution of material within the fields may be deficient [39], because they mostly start and end off-farm. When sediments are transported out of the farm borders, fine materials and organic matter which play vital roles in soil productivity might be transported outside the fields suspended in surface runoff. The large size category in the hill slope site suggests either high rainfall during the study period that was very erosive or the soils are very erodible or a combination of both. This analysis suggests there is not much difference in categories of rills in the ten farms in the two contrasting topographies. This might, therefore, be the farmer's reasons for cultivating hill slopes while flatland exists.

CONCLUSION

In this study, a survey methodology that focused on rills was employed to assess the magnitude of soil erosion from cultivated fields in two comparable topographies, situated in the northern part of Taraba state Nigeria. Assuming a 30% contribution from inter-rill erosion, soil loss was estimated at 1.501 t/ha (3.37 Mg ha^{-1} per year) in hillslope and 0.836 t/ha (equivalent to 1.87 Mg ha^{-1} per year) on the flatland. These estimates are within the lower range of soil loss due to water erosion under cultivated farms for the ecological region. The results further revealed that the proportion and contribution of the medium rills to the total soil loss and the total area of actual damage in both sites was alike. Therefore, is the farmer's reasons for cultivating the hill slope areas while flatland exist in the study region

RECOMMENDATIONS

To understand the magnitude of soil loss from cultivated farms, and the process of soil degradation due to rill erosion and the longtime practical conservation strategies to be successfully achieve. It is recommended that:

1. The best practices by the farmers from time immemorial such as Contour ploughing, intercropping uses of cover crops and mulch should be enhanced and encourage especially for hill slope farmers.
2. The expectation and perception of farmers are required to be integrated into future studies to provide empirical evidences of farmer's preference for cultivating hill slope site while flatland exist.

LIMITATIONS

A major factor that may constrain the generalizability of the present study is the small sample size. A larger size would have been more reliable. However, despite the small sub-sample sizes, the fact is that the study is the first median effort in the region to assess the magnitude of soil erosion from cultivated farms located on two contrasting topographies by using survey methodology. It is hoped that future researchers will contribute by examining with a larger sample size.

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