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Effects of Land Use and Sustainable Land Management Practices on Soil Loss, Slope Stabilization and Crop Productivity

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Abstract: ***To assess the effects of different agronomic practices and SLM on soil loss and slope stabilization, a study was conducted from 2011 to 2018 at Agriculture Research and Development Center, Wengkhar, Mongar, Bhutan. The site is located at 1750 meters above sea level (masl) between 27º 30'11'' N and 89º 52'42''E. The trial was established in Randomized Complete Block Design (RCBD) with two replications and five treatments namely i. Reference plot (kept bare throughout the year) ii. Traditional practice with local cropping method iii. Traditional practice with 2 hedgerows iv. Improved practice with legume inter-cropping along with 2 hedgerows and v. Natural vegetation. The study found significant effect ($p < 0.05$) of treatments on soil loss and slope stabilization. The maximum annual soil loss was recorded in Treatment 1 (2.69 $t^{-1}ha^{-1}yr^{-1}$) followed by Treatment-2 (2.44 $t^{-1}ha^{-1}yr^{-1}$). Though cropping area of Treatment 3 and 4 had reduced by 25%, maximum per hectare net returns were recorded in Treatment 4 (90050.00) followed by Treatment 2 (58500.00). After 8 years the gradient of site with hedgerow plantation was stabilized by about 50% with risers of 0.6 meters (m). To conclude, trying standard cultivation practice with legume intercrop in maize and planting grass hedgerow has significant benefit interms of controlling soil erosion, crop productivity and slope stabilization. Furthermore such studies should be continued in different agro ecological zones to gather precise and representative data.***

Keywords: Soil Loss; Hedgerow Plantation; Slope Stabilization; Crop Productivity

1. Introduction

Soil erosion is a major cause of land degradation in different regions of the world. It is regarded as one of the major and most widespread forms of land degradation. The magnitude of soil loss is influenced by land use and its management practices. The rate of soil erosion will be different in different land use-land cover type and different gradient. Beside, soil erosion will be triggered by amount of rainfall, its intensity and frequency. Soil erosion is a major cause of land degradation in different regions of the world. This is a particular concern for developing countries, where soil erosion by water seriously threatens agricultural productivity and food security, Lal (2003). According to Reeves (1994) combined management factors such as tillage, cover crops and plant residues can reduce soil erosion by 85%.

Management practices and attributes such as roads and trails, agricultural cultivation, fire, land clearing, and recreation all accelerate surface erosion processes due to their disturbance, compaction, and connectivity along hill slopes Sidle *et al*. (2006). The need for managing and conserving our land is very important as pointed out by Pimentel (2013) that humans worldwide obtain more than 99.7% of their food (calories) from the land and less than 0.3% from the oceans and aquatic ecosystems. Therefore, preserving cropland and maintaining soil fertility should be of the highest importance to human welfare, he added.

Numerous and different methods studies have been conducted to study the nature, intensity and effects of soil erosion across different countries since long time back. But when it comes to our context, very few have been done. As a result, the informations on the trend and amount of soil eroded, slope stabilization with SLM techniques and effect on soil erosion due to different agronomic practices are very limited. Therefore, a proper study on annual soil erosion to be in place is felt necessary.

During the implementation of Sustainable Land Management Project (SLMP), Soil Erosion Models were established in three SLMP pilot districts of Chukha, Tashigang and Zhemgang in 2008. Since then, more models have been established in different agro-ecological zones to get representative data. The model in Agriculture Research and Development Center (ARDC), Wengkhar was established in 2011. The present study was conducted to assess the rate of annual soil erosion caused by rainfall under different land management practices and assess the impact of grass hedgerow plantation in slope stabilization.

2. Materials and method

2.1. Study Area

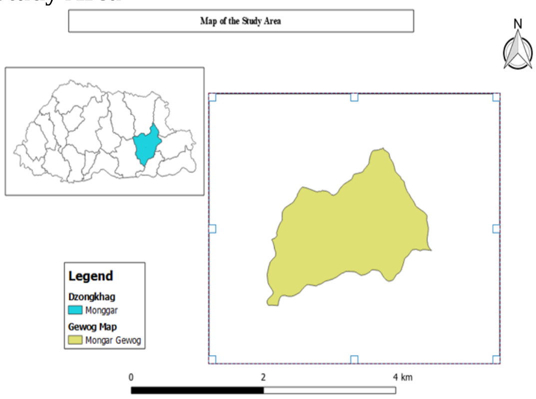

Figure 2.1: Map of study site

The experiment was conducted from 2011 to 2018 Agriculture Research and Development Center, Wengkhar, Mongar district in eastern Bhutan. The site is located at 1732 masl between 27^o 16' 09.6'' N and 91^o 16' 19.9''E. It falls under dry sub-tropical zone and faces North-west. During the last 8 years the mean annual rainfall was 906 millimeters.

2.2. Experimental setup

To assess the extent of soil erosion, and evaluate and support SLM, the experiment is designed in Randomized Complete Block Design (RCBD) in two replications. Five treatments namely i. Reference plot (kept bare throughout the year) (Treatment 1), ii. Traditional practice with local cropping method (Treatment 2), iii. Traditional practice with 2 hedgerows (Treatment 3), iv. Improved practice with legume inter-cropping along with 2 hedgerows (Treatment 4) and v. Natural vegetation (Treatment 5) were investigated.

Plot size of 10m x 4m bounded by 0.3m width of brick wall segregates each treatment. The wall is maintained at atleast 0.3m height from the ground surface. At the bottom of each plot a concrete catch-pit of dimension of 0.7m x 0.7m x 0.45m is constructed to collect sediments during rain storms. The crop cultivated was maize in three treatments and legume as intercrop in treatment iv. As a grass hedgerow, napier grass was planted in treatments iii and iv.

2.3. Data collection and Analysis

Data on quantity of seed sown in each plot, time taken in carrying out cultivation and management of the crops and yield harvested were maintained. At the end of each year soil accumulated in the catch pits were collected, air dried for one to two weeks and weighed. Composite soil samples from each treatment were collected and analyzed for both physical and chemical properties.

Data analysis were conducted using excel spread sheet and Statistical Package for the Social Sciences (SPSS) package, version 22. After checking the normal distribution of the data, analysis of variance (ANOVA) was conducted. The significance level was tested by Least Significant Difference (LSD) at significance level 0.05.

3. Results and Discussions

3.1. Soil loss

The range of annual soil loss due to rain is estimated at 0.54 ± 0.03 to 2.69 ± 0.13 tons per hectare per year (t^{-1} $ha^{-1}yr$) (Figure 3.1). The range of annual soil loss was between the ranges observed by other researchers elsewhere, though some of their findings were comparatively higher than the findings of the present study. For an instance, in a study conducted by Novara *et al.* (2011), the average annual soil erosion rate in vine yard field varied from 0.84 to 9.44 t^{-1} ha^{-1} in the field having the gradient of 15^o. Likewise, Hurni, (1983), identified that acceptable soil loss limit range of Ethiopia fall between 1 to 6 t ha^{-1}. However, in another study by Lenka, 2012 the rate of soil erosion in control plot where there was no hedgerow plantation, the soil loss of 10.68 mg t^{-1} ha^{-1} was recorded.

The annual maximum soil loss (2.69 $t^{-1}ha^{-1}yr$) was recorded in Treatment-1 followed by Treatment 2 (2.44 $t^{-1}ha^{-1}yr$). The soil loss in Treatment 1 is more than 55% and 47% compared to Treatment 4 and Treatment 3 respectively. The reasons behind may be that the soil in Treatment 1 was that the soil surface was mostly exposed and due to lack of any barrier like hedgerow to control the downward movement of runoff and soil during the periods of cultivation and management and downpours. This is as supported by the findings of Jomaa *et al*. (2012) which states that even sparse vegetation cover and rock fragments in the soil are one of the important factors in controlling soil erosion.

Cropland is more susceptible to erosion because of frequent cultivation of the soils and the vegetation is often removed before crops are planted. In addition, cropland is often left without vegetation between plantings, intensifying erosion on agricultural land, which is greater than erosion in natural forest areas, Durán Zuazo & Rodríguez Pleguezuelo (2008).

Likewise the lowest soil loss occurred in Treatment 5 (0.54 $t^{-1}ha^{-1}yr$) followed by Treatment 4 (1.21 $t^{-1}ha^{-1}yr$). This means that Treatments 5 and 4 has 79% and 55% less erosion respectively compared to Treatment 1. This is in line with the finding of Ebabu *et al.* (2019) which states that soil loss in SLM plot ranged from 38% to 94% less than in grazing plot. However, the trend of soil loss in Treatment 3 and Treatment 4 were in decreasing order over the years. This is mainly because of effect of hedgerow plantation which has acted as barrier to control downward movement of soil.

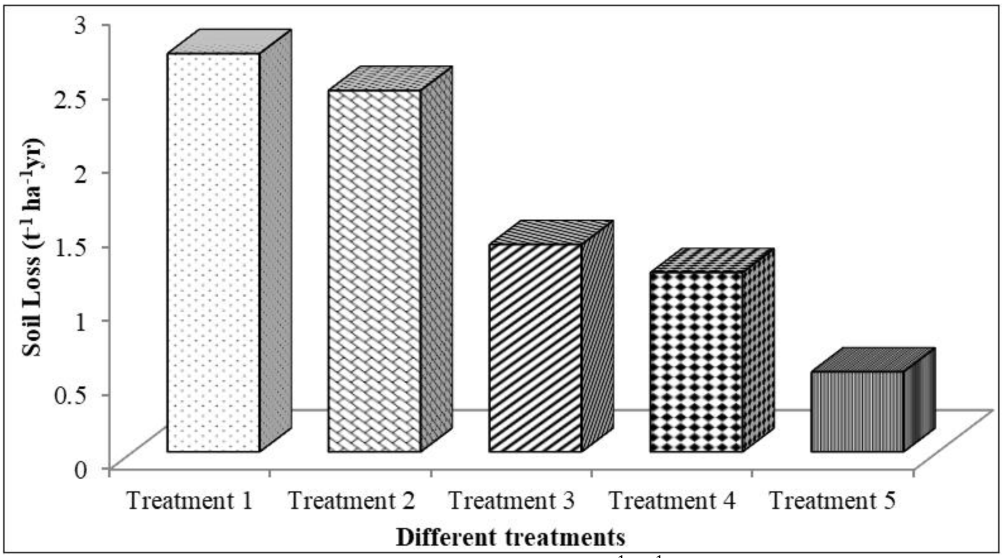

Figure 3.1: Represents the mean annual soil loss ($t^{-1}ac^{-1}yr$) in different treatments

Table 3.1: Correlation among treatments, soil loss and rainfall

Variables		Treatment	Rainfall	Soil loss
Treatment	Pearson Correlation	1	0	-.790**
	Sig. (2-tailed)		1	0
	N		40	40
Rainfall	Pearson Correlation		1	0
	Sig. (2-tailed)			0
	N			40
Soil loss	Pearson Correlation			1
	Sig. (2-tailed)			
	N			
**. Correlation is significant at the 0.01 level (2-tailed).				

The table above indicates that there is perfect linear descending relationship between the treatments and the soil loss. However, there is no linear relationship between rainfall and soil loss. It means that different treatments have negative effect on soil loss but rainfall has no effect on it.

3.2. Crop productivity

The maize production per unit was highest in Treatment 2 (1.95 $t^{-1}ha^{-1}$) followed by Treatment 4 (1.92 $t^{-1}ha^{-1}$). But when napier production is also added, Treatment 4 yielded the highest (7.55 $t^{-1}ha^{-1}$) followed by Treatment 3 (7.13 $t^{-1}ha^{-1}$). Though maize plant population was highest (160 plants) in Treatment 2 compared to Treatment 3 (120 plants) and Treatment 4 (71 plants), the maize yield harvested was just 17% and 32% higher than Treatment 3 and Treatment 4 respectively (Figure 3.2).

This may be due to poor soil fertility and limited soil moisture resulted from maximum soil erosion and absence of hedgerow in Treatment 2. According to Sidle *et al.*, 2006, the productivity of agricultural lands can be significantly reduced due to accelerated soil erosion process. This is also in line with the finding of Duan *et al.* (2016) which says that soil productivity is significantly affected by soil erosion. In another study, Lenka *et al.* (2012) reported that the grain yield of finger millet was increased by 49% from 952 kg ha^{-1} in control where there was no hedgerow plantation to 1413 kg ha^{-1} where 2 rows of hedgerows were planted. In another study, the removal of 10 cm of top soil reduced crop yield by 4.3%, Bakker, (2004).

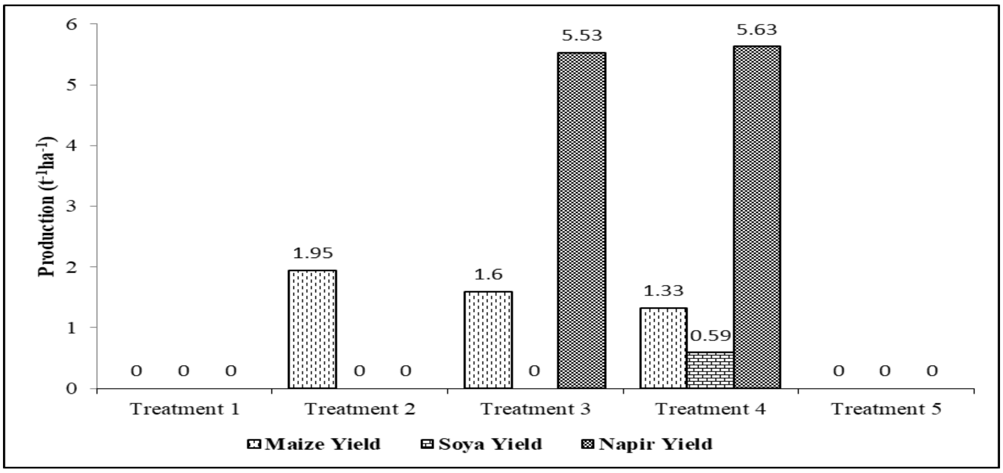

Figure 3.2: Productivity of crop and forage under different treatments

Table 3.2: Represents the returns from crops grown in different treatments

Variables	Mean maize production (t^{-1} ha^{-1})	Rate/kg (Nu.)	Total (Nu.)	Mean soya bean yield (t^{-1} ha^{-1})	Rate/ kg (Nu.)	Total (Nu.)
Treatment 2	1.95 ± 0.03	30.00	58500.00	NA	NA	
Treatment 3	1.60 ± 0.01	30.00	48000.00	NA	NA	
Treatment 4	1.33 ± 0.02	30.00	39900.00	0.59 ± 0.26	85.00	50150.00

When calculated based on National Seed Center's selling rate, 2018 the maximum returns was generated from Treatment 4 (Nu. 90050.00) followed by Treatment 2 (Nu. 58500.00) without calculating return from napier grass. This indicates that intercropping soya bean with maize and having napier hedgerow plantation is far more profitable.

3.3. Cropping area

Table 3.3: Represents the initial and reduced cropping areas of three treatments

Variables	Initial (2011)	After 8 years	Maintained at present
Treatment 2	40 m^2	40 m^2	40 m^2
Treatment 3 and 4	39.2 m^2	30.03 m^2	35 - 37.6 m^2

The cropping area in Treatment 2 has been 40 square meter (m^2) since the establishment of trial in 2011. However, considering the initial space occupied by napier plantation at 0.8 m^2, the area leaf for cropping maize and soya bean was 39.2 m^2. Over the years of cultivation, the hedgerow plantation had expended and reduced the cropping area of Treatments 3 and 4 to 30.03 m^2 which came to almost 25% less than Treatment 2. Therefore, at the end of 8th year the napier that had over expended and occupied more space had been dug, trimmed and removed maintaining its area to 2.4 m^2 in Treatment 3 and 4.

3.4. Slope stabilization and riser formed

Table 3.4: Represents initial and present gradients of the treatments

Variables	Initial gradient (Degrees)	Gradient after 8 years (Degrees)	Riser formed (m)
Treatment 1	19°	19°	NA
Treatment 2		19°	NA
Treatment 3		9.7°	0.35
Treatment 4		9.5°	0.46
Treatment 5		19°	NA

Initially when the trial was established in 2011, the gradient of the site was 19 degrees. Due to naiper hedgerow plantation, the slopes in Treatment 3 and 4 had reduced to 9.5 and 9.7 degrees respectively. This means that the gradient in those treatments have stabilized by 48.9% and 50% respectively. Likewise, the riser formed in Treatment 4 (0.46m) is more than Treatment -3 (0.35m). This may be due to more accumulation of soil because of better ground cover which has resulted in very slow movement of the soil.

4. Conclusion

According to the findings of the research, hedgerow plantation has greater impact on controlling surface runoff and helps reduce soil erosion. This also helps in stabilization of gradient over a period of time. However, considering the reduction in cropping area due to expansion of the hedgerow plantation, managing the hedgerow by trimming and removal every after 5 is found helpful. On the other hand, looking at the maximum returns from the plot where improved cultivation is practiced coupled with SLM and legume intercropping such practice is recommended to the farmers considering the limited hand holding and rugged terrain of our country.

Since the soil degradation and its impact to mankind is felt after long time impact, such study needs to be replicated and continued further to gather precise national information. Apart from this, studies on workability and economic impacts have to be carried on to get better understanding of SLM impact. On the other hand, establishment of more such runoff plots at different agro-ecological zones would represent the country's annual soil loss more adequately.

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