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Full Length Research Paper

Soil and nutrient losses in banana-based cropping systems of the Mount Elgon hillsides of Uganda: economic implications

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This study investigated the effect of different farmer cropping and soil conservation practices on runoff, soil and nutrient loss in Bududa district, Uganda. Gerlach troughs measuring 0.6m length, 0.4 m width and 0.5 m high were installed on runoff plots (15 m x 2 m) on farmer's fields under banana sole, banana-arabica coffee or annual crops, with or without soil conservation structures. Soil loss was significantly (P<0.05) higher on annuals than on banana or banana-coffee (38.5 vs 6.6 vs 0.87 t $ha^{-1}yr^{-1}$), with values much higher for fields without conservation structures compared to those where there were structures. The total monetary value for NPK lost through erosion was US $ 16,663, 4,404 and 442 $ha^{-1}yr^{-1}$ for annuals, banana and banana-coffee fields respectively; with values much higher for fields without conservation structures compared to those with structures (US $ 15,451 vs 6,058). Soil loss values were much higher than the tolerable limit for Uganda which is 5 t $ha^{-1}yr^{-1}$ and calls for immediate action to scale up sustainable land management practices.

Key words: Land degradation, management practices, monetary value, soil erosion, valuation.

INTRODUCTION

Runoff and soil erosion are major land degradation processes in East Africa, contributing immensely to nutrient depletion, declining agricultural productivity and income. In Uganda, soil loss rates recorded in different locations are higher than the tolerable values (Bagoora, 1990) and have raised both ecological and environmental concerns. Highlands occupy around 25% of Uganda's land and contain 40% of the country's population. They are found in the Southwest, East, West and Northeastern regions, have steep slopes, high population densities and most land including marginal lands, is under intense cultivation. Bududa is among the areas badly affected by soil erosion with 75 to 80% of the district affected (NEMA, 2001). There is as yet little evidence that increase in population densities has led to sufficient adoption of land management practices to offset the worsening erosion and nutrient depletion (Nkonya et al., 2002).

Soil erosion has been a major problem since before independence (Carswell, 2002), and continues even today, with severe impacts (NEIC, 1994; Kazoora, 2002). It is estimated that 4 to 12% of gross domestic product (GDP) is lost through environmental degradation (Slade and Weitz, 1991; NEMA, 2001), 85% of this from soil erosion, nutrient loss and changes in crops (Olson and Berry, 2003). The total monetary value of environmental degradation was estimated at U$170 to 460 million p.a.

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in 1991 and by 2003, this was put at 230 to $600 million (Kazoora, 2002).

Removal of nutrient-enriched soil from cropland leads to a decline in per capita food production (Dunne and Dietrich, 1982). This is a serious menace to the future of an expanding and poor population, whose only resource is a small portion of land, exploitable at subsistence level (Sanchez et al., 1997). Land degradation culminates in a vicious circle of low income-low input, low yield and poverty (Crosson, 1995; Berry et al., 2003). At a farm level, declining fertility is worst on fields far from the homesteads since available organic materials such as manure and crop residues, are placed only on fields nearest the homestead.

With arable land per capita expected to decline from 1.1 ha in 1991 to 0.6 ha in 2015 (NEMA 2001), it is critical to both reduce land degradation trends in areas already under cultivation, and ensure sustainable land management practices to prevent degradation in future cultivated areas. Erosion control bunds had been installed by the colonial administration in the Mt. Elgon area and some are still being maintained by farmers. However, attitude towards further expansion is poor partly due to high labour demands. Further, use of inputs, such as chemical fertilizers and manure, is very low.

Runoff and soil loss studies in agricultural lands have shown that the effectiveness of various management practices in reducing soil loss depends strongly on the characteristics of climate, crops and soil (Shipitalo and Edwards, 1998; Wan and El-Swaify, 1999). Use of appropriate management practices can decrease erosion and increase available soil water for crops. Regional differences in soil physical properties partly explain the different results from various runoff studies.

Soil and water losses fluctuate highly between different seasons and years (Majaliwa et al., 2005; Merz et al., 2006). These fluctuations complicate accurate erosion measurement and prediction (Hogarth et al., 2004). Moreover, such intra- and inter-annual changes in water erosion are complex and caused by many synergistic factors (Busnelli et al., 2006), such as variations in rainfall (Wei et al., 2009; Baigorria et al., 2007), slope, land use and soil characteristics. Wejuli (2008) found that soil erosion in Wanale watershed of Uganda was a function of land cover, soil erodibility and the square root of slope. Deforestation, cultivation of steep slopes and other agricultural activities have induced severe erosion and land degradation in huge areas around the world (Gafur et al., 2003). Loss of vegetation cover as a result of human activities such as overgrazing and deforestation leads to formation of soil seals that increase the risk of runoff and soil erosion (Singer and Shainberg, 2004; Snyman and duPreez, 2005).

Understanding runoff and soil erosion processes under different land characteristics and uses, and the impacts of land use, cultivation and slopes, is essential for sustainable agriculture since most annual global soil erosion rates are observed from farmlands (Wilkinson and McElroy, 2007). Appropriate land use and management can increase rainfall infiltration and reduce surface runoff and soil losses. Vegetation restoration can also improve the effectiveness of land cover, consolidate the health and stability of local ecosystems, and reduce the sensitivity of soil erosion and water loss to temporal changes in rainfall (Dunjó et al., 2004; Merz et al., 2006; Eugenia et al., 2007).

Studies by Bamutaze et al. (2010) indicate that current runoff; erosion and sedimentation rates in the Mt. Elgon Manafwa district are generally high. Mean soil loss rates varied significantly ($P<0.05$) from 7.5 in perennial to 24 t $ha^{-1}yr^{-1}$ in annual land uses.

The rates were above the tolerable rate of 5 t $ha^{-1}yr^{-1}$ for Uganda, with annuals on steep slopes generating more sediment. While many studies have quantified soil erosion, the monetary value of soil loss has not been adequately assessed in Uganda.

Economic valuation method of soil erosion

The effects of soil degradation have been reported in declining crop yields, siltation of water bodies, reduced fish catches, water hyacinth infestation, to mention but a few. Actual yields of grain crops ranged from 51 to 68% of potential crop levels (Bashaasha et al., 2001). Many approaches have been used to establish the economic value of soil erosion (Clark, 1994).

Some of the commonly used methods are replacement cost, rehabilitation cost, contingent valuation, hedonic pricing, market value of soil, production value of soil, opportunity cost etc. Each method operates from different perspectives and has inherent drawbacks (Hacisalihoglu et al., 2010).

According to Jayasuriya (2003) the “market value of soil” method estimates the cost of soil erosion to society as a whole.

The approach is based on soil erosion reducing the productive potential of the soil through depletion of the soil’s nutrient content, its physical structure and ecological qualities. Of these factors, only the soil’s nutrient content can be valued in terms of marketed proxies (artificial fertilizers).

Therefore, the analysis estimates the value of reduction in soil’s productive potential in terms of depletion of the soil’s nutrient resource base. It is calculated as the market value of the difference in soil nutrient content between an eroding soil and uneroded soil. The method undervalues the soil from society’s perspective. The soil nutrients are valued in terms of their least cost artificial fertilizer equivalents.

The analysis is not based on the soil nutrient replacement cost approach (Jayasuriya, 2003).

Objectives

1. To determine the effect of different cropping and soil conservation practices on runoff, soil and nutrient losses.
2. To assess the market value of the nutrient losses incurred under different cropping and soil conservation practices.

MATERIALS AND METHODS

Description of the study sites

The study was carried out in Bushika Sub County (Bushiunya, Bumushisho and Bunabutiti parishes) in the Mt. Elgon Bududa district, Eastern Uganda. Bududa district lies between latitude 2° 49’ N and 2° 55’ N, longitude 34° 15’ E and 34° 34’ E. The area receives above 1500 mm yr^{-1} rainfall, controlled by the high altitude of 1250 to 2850 m (Kitutu et al., 2009). It has two distinct wet seasons, separated by dry periods during December to February and July (The Republic of Uganda. 2004). Temperature ranges from 7.5 to 27.5 °C. The cropping pattern is dominated by banana, arabica coffee and annuals.

Soil characterization

Detailed soil description in the study area was carried out on representative soil unit profiles (0 to 1.5 m) of major landscapes using FAO guidelines (FAO, 1990). Vegetation, slope, GPS coordinates, physiography, erosion, topography, stoniness, geomorphic position, and drainage with potential to influence soil properties were also recorded. Morphological parameters considered in soil description included colour, depth, horizon boundary, structure, texture, consistency, compactness, porosity and cementation, slope, land use/cover, stoniness, abundance and diversity of roots and macro-organisms. Representative soil samples were collected from each horizon for laboratory analysis of texture, pH, organic carbon (OC), exchangeable Ca, Mg, K, Al, available P and CEC (Okalebo et al., 1993). For fertility assessment, soil samples (0 to 20 cm) were taken from each experimental plot, dried at 40°C for 3 days, ground to pass 2 mm sieve and analysed for pH, OC, available P, exchangeable Ca, Mg, K, total N and particle size distribution using standard methods (Okalebo et al., 1993).

Three dominant soil units were identified: Rhodic Nitisols, Ferralic Nitisols and Haplic Lixisols Skeletic (data not presented). Rhodic Nitisols and Ferralic Nitisols occupy foot-slope and shoulder positions of the undulating topography, characterized by distinct red colours in the A layer extending into a deep B layer that goes beyond 1.2 m. The A and B horizons are separated by a wavy boundary. Haplic Lixisols Skeletic soils occupy the upslope position and are shallower with a pronounced rocky structure. They are rich in nutrients with a base saturation of 50 to 80% in the surface layer. Soils are susceptible to erosion due to high slopes that characterize the terrain. The identified soil units are in agreement with those reported for this area (Isabirye et al., 2004).

Rainfall measurements

Three rain gauges were installed in each of the three parishes where the experimental plots were located, and the amount of rainfall recorded for each rain event. Daily rainfall was measured using conventional rain gauge with a measuring cylinder (CASELA type 127 mm diameter, Department of Meteorology, 1979). The data collected included: rainfall duration, amount and any special remarks about the storm.

Experimental set up

While it is acknowledged that slope has a very significant influence on soil erosion and runoff, the major focus of this study was to examine the effect of farmers’ management practices on runoff, soil and nutrient loss. Study fields were located on slopes ranging from 3 to 45%. The experiment variables consisted of (i) farmers’ cropping practices (banana, banana-arabica coffee, annual crops) and (ii) soil conservation structures (terraces) used or no structures used. Farmers were carefully selected to represent each combination of cropping (banana, banana-arabica coffee, annual crops) and soil conservation practices (structures (terraces) or no structures). Twelve (12) farmers were selected from each parish, with each of the three parishes representing a replicate. Gerlach troughs measuring 0.6 m length, 0.4 m width and 0.5 m high were installed onto experimental plots measuring 15 × 2 m, on 36 farmers’ fields. Runoff from each plot was collected in the trough every rainfall event. Experimental set up was a factorial combination of cropping practices and conservation practices in a completely randomized design, replicated 3 times (parishes).

Determination of runoff, soil and nutrient loss

Using a steel meter rule, farmers recorded the height (cm) of the runoff mixture collected in the trough after every rainfall event. The mixture was stirred uniformly and a sample of the soil-water suspension taken in a 3 L jerrycan for laboratory analysis. The volume of solution in

Table 1. Summary of selected soil characteristics (0 to 20 cm) for the study sites.

Parish (REP)		pH	OC	N	P	Ca	Mg	K	Sand	Clay	Silt
			-------%-------		--------------- (mg kg^{-1}) ---------------				--------------%-----------		
Bunabutiti	Mean	6.3	3.1	0.2	12.1	3193	677.9	1147	33.4	52.4	14.2
	Standard deviation	0.7	1.3	0.1	17.1	1731	317.2	800.6	15.5	16.1	4.9
Bumushisho	Mean	5.9	2.3	0.1	3.2	2149	527.5	464.3	50.4	40.6	9.0
	Standard deviation	0.2	0.9	0	4.2	468	113.8	516.1	9.6	12.3	3.6
Shunya	Mean	5.8	3.4	0.2	13.3	3181	648.2	405.6	36.7	47.7	15.5
	Standard deviation	0.4	1.9	0.1	11	1173	192.7	302.1	13.6	11.8	11.4
Overall mean		6.0	2.9	0.2	9.5	284	617.9	672.3	40.2	46.9	12.9
Mean Standard deviation		0.4	1.4	0.1	10.8	1124	207.9	539.6	12.9	13.4	6.6

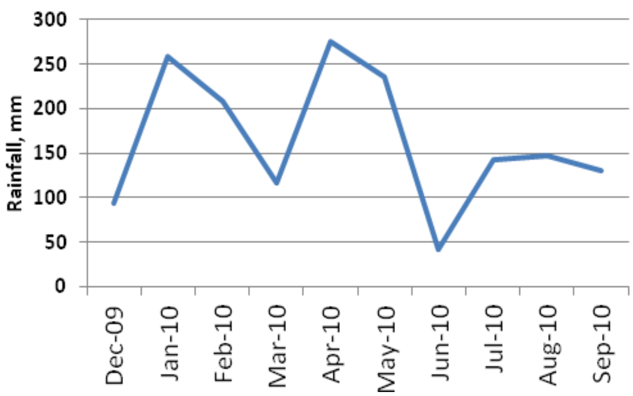

Figure 1. Mean monthly rainfall for Bushika sub county, Dec. 2009 to Sept. 2010.

the trough was obtained by converting the height of water (cm) from the 15 by 2 m plot to m^{3}ha^{-1}, and summed up to obtain m^{3}ha^{-1}yr^{-1} for each land use and conservation practice. The amount of soil sediment within the sampled volume was determined after decanting off the clear water. The sediment was dried, weighed and reported as soil loss in kgha^{-1}, then summed up to kgha^{-1}yr^{-1} or tha^{-1}yr^{-1}. Nutrient (NPK) loss was calculated by multiplying soil N, P and K content (kg kgsoil^{-1}) by soil loss (kg ha^{-1}), and later summed up to obtain the kg NPK ha^{-1}yr^{-1}. From the market price of N, P and K fertilizers, the monetary value of the lost nutrients was computed.

Data analysis

Data were processed using Microsoft Excel and statistically analysed using Genstat package version 3.2. Significant differences between means were determined at a 95% Confidence level and means separated using the standard error of difference (sed) procedure. Two means were declared as significantly different when the difference between them was greater than twice the sed value.

RESULTS AND DISCUSSION

Soil characteristics

Table 1 presents mean soil characteristics for the study sites. Difference in the three parishes was evident in the soil properties. The soil pH was higher for Bunabutiti compared to the other two parishes. However, pH values were above the critical value of 5.2 for Uganda soils. Soil OC, N and P were higher for Shunya and lowest for Bumishosho. Higher OC, N and P values for Shunya are understandable considering that being adjacent to the park, land in this parish is relatively more recently opened compared to Bunabutiti and Bumushisho parishes which have been cropped for a longer period. Averaged over the 36 farmers' plots, soil pH$_{water,}$ was 6.0; mean OC was 2.9% while mean N was 0.14. The P averaged 9.51 mgkg^{-1} (Table 1).

Rainfall distribution for Bushika Sub County, December 2009 to September 2010

Figure 1 presents mean rainfall distribution during the study period. Data are means of 3 parishes (Bushiunya, Bumushisho and Bunabutiti). Peak rain periods were observed during January and April 2010, with low rainfall periods between June and September 2010. These spatial variations in rainfall would be expected to influence runoff and erosion measurements (Yair and

Table 2. Effect of land use and conservation structures on runoff and soil loss.

Parish (REP)	Soil loss, t $ha^{-1}yr^{-1}$	
	No structures	Structures
Bunabutiti	2.34	1.68
Bumushisho	1.56	4.39
Shunya	2.75	0.77

Land use	No structures	Structures
Annuals	38.5	15.5
Banana	6.6	3.2
Banana-coffee	0.9	0.2
sed	6.07	
CV, %	18.2	

Raz-Yassif, 2004; Nearing et al., 2005).

Effect of land use and conservation structures on runoff and soil loss

Runoff ranged from 129 to 2,394 with a mean of 858 $m^3ha^{-1}yr^{-1}$. However, this was not directly related to land use or soil conservation practices (data not shown). Soil loss was higher for Shunya parish and lowest for Bumushisho. With the exception of Bumushisho parish, soil loss values were higher for fields with no conservation structures compared to those with structures. Soil loss was significantly (P<0.05) higher on annuals than on banana or banana-coffee (38.5 vs 6.6 vs 0.87 t $ha^{-1}yr^{-1}$), with values much higher for fields without conservation structures compared to those with conservation structures (Table 2). Soil loss values experienced on annual and banana crop fields were much higher than the tolerable limit for Uganda which is 5 t $ha^{-1}yr^{-1}$. Studies by Bamutaze et al. (2011) in the Mt. Elgon district of Manafwa, revealed high runoff and erosion rates, with soil loss being 7.5 $tha^{-1}yr^{-1}$ on perennials and 24.0 $tha^{-1}yr^{-1}$ on annual crops. In the L. Victoria basin Rakai district (heavy clay soils, 914 to 1118 mm rainfall), Majaliwa et al. (2005) reported runoff from annual crop fields to range from 315 to 2,439 $m^3ha^{-1}yr^{-1}$ and soil loss of 27.7 to 86.7 t $ha^{-1}yr^{-1}$, with higher values reported for annual crops than perennials. Data from the present study show that runoff from annual crop fields in the Mt. Elgon Bududa district (light volcanic soils, over 1500 mm rainfall, more steep slopes) could even be higher than that in the L. Victoria basin.

The dependence of runoff and soil loss on land use has been attributed to factors such as rainfall, topography, canopy cover, ground cover, and soil properties (Majaliwa et al., 2005). In this landslide-prone Bududa district, land management systems which leave the land devoid of vegetation cover (e.g. annual cropping) are likely to result in severe erosion, which could aggravate the situation. Banana and coffee present a relatively good canopy cover compared to annuals crop fields which are bare at the beginning of rainy seasons (Majaliwa et al., 2005).

Effect of land use and conservation practice on nutrient loss

Organic carbon (OC) loss was significantly (P<0.05) higher on annuals than banana or banana-coffee systems (1,111 vs 224 vs 24 kg $ha^{-1}yr^{-1}$, Table 3) with values higher for fields without compared to those with conservation structures. The N lost followed a similar trend to that of OC; values were significantly (P<0.05) higher for annual crop fields compared to banana or banana-coffee fields (6,581 vs 1,581 vs 185 kg $ha^{-1}yr^{-1}$, P<0.05). The mean P lost ranged from 0 to 0.87 kg $ha^{-1}yr^{-1}$. The values were higher for annual crops compared to banana or banana-coffee, however the means were not significantly (P>0.05) different between land use or conservation practices. Values for K and Mg lost were also higher for annual crops compared to banana or banana-coffee plots, although not significantly (P>0.05) different between land use of conservation practices. According to Hacisalihoglu et al. (2010) nutrient loss from agricultural land in semi-arid (400 mm) part of Turkey amounted to 0.84 to 1.44, 0.67 to 1.30 and 9.42 to 14.90 kg $ha^{-1}yr^{-1}$ for N, P and K, respectively. Results from the present study show even higher NPK losses from the wetter (over 1,500 mm) mountainous Bududa district.

The monetary value of nutrients (N, P and K) lost due to soil loss

The monetary value of soil loss in the research area was calculated using the method “market value of soil” basing on the lowest nutrients market prices (Hacisalihoglu et al., 2010). Nutrient prices were determined from the lowest fertilizer prices in Kampala as of 2010. The following values were used: urea (46%N, US $ 42.50 per 50-kg bag); triple superphosphate (TSP, 45% P_2O_5, US $ 47.50 per 50-kg bag); muriate of potash (MOP, 50% K_2O, US $ 45.0 per 50-kg bag). Based on these prices, the cost per nutrient was determined as US $ 1.85, 4.75 and 2.20 per kg of N, P and K, respectively.

Results show that the monetary value of N loss was highest in Shunya parish on fields without conservation structures. This is due to both the high soil and nutrient losses which were highest for this parish compared to others (Tables 2 and 3). However, for P and K, the trends were different.

Table 3. Nutrients lost under different land use and conservation practices.

PARISH (REP)	OC lost, kg $ha^{-1}yr^{-1}$		Nitrogen lost, kg $ha^{-1}yr^{-1}$		Phosphorus lost, kg $ha^{-1}yr^{-1}$		Potassium lost, kg $ha^{-1}yr^{-1}$	
	No structures	**Structures**	**No structures**	**Structures**	**No structures**	**Structures**	**No structures**	**Structures**
Bunabutiti	7717	5904	459	332.2	0.08	0.04	2.09	1.11
Bumushisho	4875	1129	329	74.9	0.06	0.00	3.24	0.28
Shunya	7452	1815	544	240.1	0.04	0.01	3.19	0.23
Land use	No structures	Structures	No structures	Structures	No structures	Structures	No structures	Structures
Annuals	1,111	451	6,581	2,354	0.34	0.87	38.8	28.2
Banana	224	101	1,541	828	0.18	0.11	6.6	5.6
Banana-coffee	24	4	185	54	0.00	0.00	0.40	0.10
sed	191	NS	1234.8	NS	NS	NS	NS	NS
CV, %	27.8		30.5		82.1		39	

Table 4. The monetary value of nutrients (N, P, K) lost due to soil erosion.

Land use	Loss through N loss, US $/ha/yr		Loss through P loss, US $/ha/yr		Loss through K loss, US $/ha/yr		Total loss through NPK, US $ $ha^{-1}yr^{-1}$
	No structures	**Structures**	**No structures**	**Structures**	**No structures**	**Structures**	
Bunabutiti	849.110	614.562	0.399	0.167	4.602	2.438	1471.28
Bumushisho	608.723	138.665	0.292	0.005	7.131	0.623	755.44
Shunya	1006.268	444.135	0.187	0.025	7.027	0.504	1458.146
Annuals	12,160	4,350	1.61	4.15	85	62	16,663
Banana	2,847	1,530	0.83	0.5	14	12	4,404
Banana-coffee	342	99	0.01	0.01	1	0	442
sed	2,282		1.915		36.7		
CV, %	30.5		82.1		38.9		

The value of N lost was significantly higher for annual crops compared to banana or banana-coffee (US $ 12,160 vs 2,847 vs 342, P<0.05) (Table 4), with values higher for fields without compared to those with conservation structures. A similar trend was observed for P and K. Cumulatively for the 3 nutrients (N, P, K), a total of US $ 16,663, 4,404 and 442 $ha^{-1}yr^{-1}$ was lost from annuals, banana and banana-coffee fields respectively, through soil erosion. Total nutrient values were much higher for fields without compared to those with conservation structures (US $ 15,451 vs 6,058). Studies by Hacisalihoglu et al. (2010) showed that the economic value loss due to soil erosion from agricultural land in a semi-arid area of Turkey (400 mm rainfall) was US $ 102 $ha^{-1}year^{-1}$. Results of our study suggest even much higher rates for the wetter (>1500 mm rainfall) mountainous district of Bududa.

Financial implications of soil and nutrient loss

Soil nutrients (e.g. NPK) are contained mainly in organic matter (OM) and clay particles. Since OM is concentrated mainly in the top 0-30 cm part of the soil layer, runoff and soil erosion processes result in loss of these essential plant nutrients. Extensive soil erosion in the mountainous regions leads to continuous loss of essential nutrients, leading to a progressive decline in crop yields. Replacing the lost nutrients necessitates purchase of fertilisers. With the high fertiliser prices in Uganda, replacing the lost nutrients definitely impacts negatively on the resource poor farmers.

SUMMARY AND CONCLUSIONS

This study investigated the effect of different farmer cropping and soil conservation practices on runoff, soil and nutrient loss. Soil loss was significantly (P<0.05) higher on annuals than on banana or banana-coffee (38.5 vs 6.6 vs 0.87 t $ha^{-1}yr^{-1}$), with values much higher for fields without compared to those with conservation structures. Organic matter, N, P and K losses followed a similar trend to that of soil loss, with higher values observed for annuals than banana and lowest on banana-coffee; higher values were observed from fields without conservation structures compared to those with structures. Cumulatively, the total monetary value for NPK lost through erosion was was US $ 16,663, 4,404 and 442 $ha^{-1}yr^{-1}$ for annuals, banana and banana-coffee fields respectively. The total nutrient values are much higher for fields without conservation compared to those with structures (US $ 15,451 vs 6,058 $ha^{-1}yr^{-1}$). The soil loss values experienced in this study (annual and banana crop fields) were much higher than the tolerable limit for Uganda which is 5 $tha^{-1}yr^{-1}$ and this calls for immediate action to address the situation by scaling up sustainable land management practices in the area.

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