Runoff, Soil and Nutrient Losses from Major Agricultural Land-use Practices in the Lake Victoria Basin, Uganda

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ABSTRACT

Soil degradation by water erosion is recognized to be a major agricultural and environmental problem in the Lake Victoria basin. The objective of this study was to quantify runoff, soil and nutrient losses from major agricultural land-use types (Annual crops, banana, coffee and degraded rangelands) and assess the efficiency of contour bunds in reducing these losses in two selected micro-catchments of the Lake Victoria Basin. The experiment was conducted on 13 runoff plots of 15 by 10 m. Each land-use type was replicated three times, except banana. Contour bunds were hand constructed two years after establishment of runoff plots, at 20-m spacing interval. Before the establishment of contour bunds, the average annual runoff ranged between 315. 47 and 2438.92 m^3 ha^{-1}/yr, with relatively higher amount of rainfall water loss on rangelands compared to banana and coffee ($p=0.022$). The avarage annual soil loss ranged from 27.7 to 86.7 t/ha/yr, with higher soil loss on annuals compared to banana and coffee ($p=0.038$). Seasonal soil losses contributed for more than 75% of the annual losses for all agricultural land-use, while seasonal runoff contributed the same proportion only for banana and rangelands ($p<0.05$). Eroded sediments had relatively high nutrient concentrations than the remaining soils, and varied with land-use and /or seasons ($p<0.05$). The amount of N, P, K and organic matter (OM) lost through erosion was relatively high, and varied with seasons ($p<0.05$). The establishment of contour bunds increased OM, Ca and Na content in eroded sediments, while it decreased total OM, TN losses for all land-use types except on rangelands where they increased one year after. These exports from agricultural land play a major role in the nutrient enrichment of rivers and open bodies.

Key words: Pollution, Sustainability, Farming system, Land-use, Soil nutrient losses.

INTRODUCTION

The most prevalent forms of soil degradation in East-Africa and indeed in the world, is nutrient depletion and soil erosion (Larson, 1983 ; El-Swaify, 1982 ; AID, 1988 ; Lal, 1989 ; Oldeman *et al.,* 1990 ; Sanders, 1992 ; Stocking, 1995 ; Magunda and Tenywa, 2001). In Uganda, soil loss rates recorded in different locations are higher than the tolerable values (Bagoora, 1990 ; Majaliwa, 1998) and has raised both ecological and environmental concerns in the country. This status may be associated with over exploitation of available resources and expansion of certain land-use practices in unsuitable environment, which severely degraded vegetation cover (Mokwunye *et al.,* 1996).

Ecological concerns are related to the problem of environmental quality, in general, and pollution of water bodies, in particular. The Lake Victoria crescent receives unfavourable climatic fluctuation characterized by heavy storms generating considerable runoff which could then be loaded with relatively rich soil nutrients. The removal of nutrient enriched soil from crop land leads to the *per capita* food production decline (Dunne and Dietrich, 1982; Pieri, 1989; Sanchez et al., 1996). 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.,* 1996). The net result of the ongoing degradation may culminate in a vicious circle of low income-low input, low yield (GTZ, 1995; Crosson, 1995).

Part of runoff and sediment generated from different land-uses including croplands always ends up in drainage networks (Johnes, 1996). Lake Victoria and its tributaries are already showing signs of enrichment (Hecky, 1993). Past surveys on eutrophication and pollution point agricultural land as proximate cause on the on going degradation in the waterbodies (Edwards and Blackie, 1981; Chabeda, 1983).

In the catchment, the key for sustainable use of resources passes by the identification of effective pollutants areas, quantification of nutrient flows from different land-use practices, and identification of possible succesful mitigating measures. Best management practices (BMP) represent also a wide range of widely used technical opportunities which aim at protecting, enhancing, or rehabilitating degraded lands. In the Lake Victoria catchment, contour bunds are among candidate BMPs. Contour bunds are expected to reduce slopes effect, and allow water to remain on the surface for a relatively longer period, thereby increase infiltration and reduce runoff. As a consequence erosion and sedimentation are expected to be cut off to some extent, with attendent impact on the aquatic ecosystem, up and down stream characteristics, and adjacent land features as well.. The objective of this study was to determine the magnitude of runoff, soil and nutrient losses from major agricultural land-use practices in the Lake Victoria Basin, and assess the impact of contour bunds on the nutrient losses.

MATERIALS AND METHODS

The experiments were conducted in two selected micro-catchments of Lake Victoria Basin. The two micro-catchments are located between 0 35' - 1 00' S and 31 15' - 31 48' N (Figure 1). The climate is characterised by a bimodal rainfall regime. The long rains start in March and end in May, while the short rains fall between October and December. Annual precipitation ranges between 914 mm and 1118 mm. The mean monthly temperature is 23 ° C. The sub-catchment is drained by river Kibale as major tributary to the Lake Victoria.

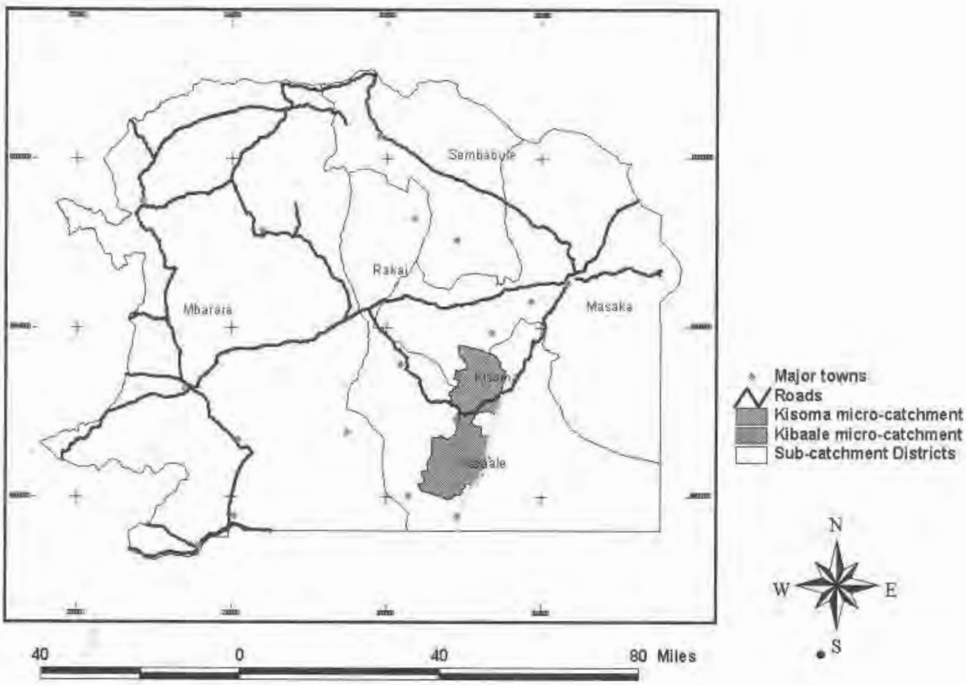

Figure 1: The study area (Kibaale and Kisoma micro-catchments)

The geology/geomorphology consists of highly dissected plateau underlain with phillites. The soils are *petroplinthic plinthosols* and *hyperskeletic leptosols* at the summit, shoulder and upper backslopes of the flat topped ridges and round topped hills, and *haplic luvisols* on footslopes (Ssali and Isabirye, 1998). The vegetation cover follows the physiographic pattern of the landscape. The tops of plateau are covered by *Themeda-Loudentia* grass savanna, and the ill-defined pediments and vales are covered by a dry *Acacia* savanna with *Themeda* spp and *Bacharia* spp. dominating as ground cover. The agricultural system is mainly subsistence with small-scale cash agriculture. Three broad land-use practices were identified in Rapid Rural Appraisal and Participatory Rural Appraisal in the area namely grazing, forest, and mixing-cropped land.

Thirteen runoff plots of 15 by 10 m were established in 1998, on farmers' fields, representing the four major agricultural land-use types in the area annuals, banana, coffee and degraded rangelands. Runoff plots were left to farmers management. Each agricultural land-use type was replicated three times, except banana which was replicated four times with two plots mulched and two unmulched. Runoff plots'steepnesses ranged between 14 and 15% for coffee and banana, and 29 and 49 % for rangelands and annual crops. Depending on the slope steepness, soil type and management, one or two divisors were inserted between the runoff gutter and the tank for runoff partition. Soil and runoff losses from each runoff plot were determined after each storm. One litre composite runoff sample was collected and oven dried to determine the amount of suspended sediment. In addition, a portion of a maximum 100 g of eroded sediments collected from the divisor and/or tank was air dried, and then bulked on a seasonal basis and analyzed for nutrient concentration using methods described by Foster (1971). Two years after establishment of runoff plots (end of 1999) contour bunds were hand-constructed at a spacing of 20 m around the runoff plots and runoff, soil and nutrient losses were monitored for one year (2000). Soils were sampled at the beginning of the experiment (1998) and in 2000 at depth of 0-15 and 15-30 cm, and then analysed also for routine nutrient content. Soil nutrient concentrations were determined according the standard methods decribed by Okalebo *et al.*, (1993). The total nutrient loss per agricultural land-use type per unit area through surface runoff was obtained by multiplying the nutrient concentration by the associated soil loss. The total rainfall amount was recorded daily from rain gauges installed at each experimental site. The average rainfall intensity was esimated according to the rainfall duration.

RESULTS AND DISCUSSIONS

Soil and runoff losses

Annual soil and runoff losses were dependent on land-use practice and showed high variability across years. The average annual soil loss and runoff from the four agricultural land-use types of the Lake Victoria catchment are presented in Figure 2 and 3.

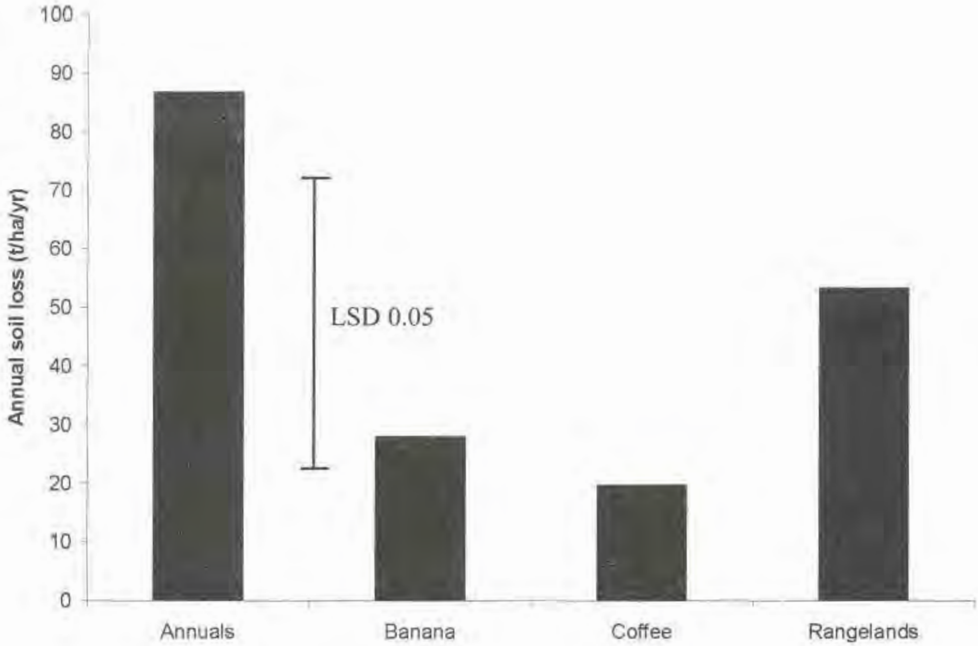

Figure 2: Mean annual soil loss from major agricultural land-use types in the Lake Victoria Basin. (Mean of two years 98-99)

The average annual soil loss ranged from moderate to high (FAO, 1979). It was relatively high on annuals compared to banana and coffee (p=0.038). The average annual runoff ranged between 315. 47 and 2438.92 m^3 ha^{-1}. Degraded range lands lost relatively higher amount of rainfall water through surface runoff compared to banana and coffee (p=0.022). Surface runoff represented a relatively small fraction of the rainfall input especially for annuals (1%), banana (0.3%), and for coffee (0.8%). Degraded rangeland lost 23% of rainfall as surface runoff.

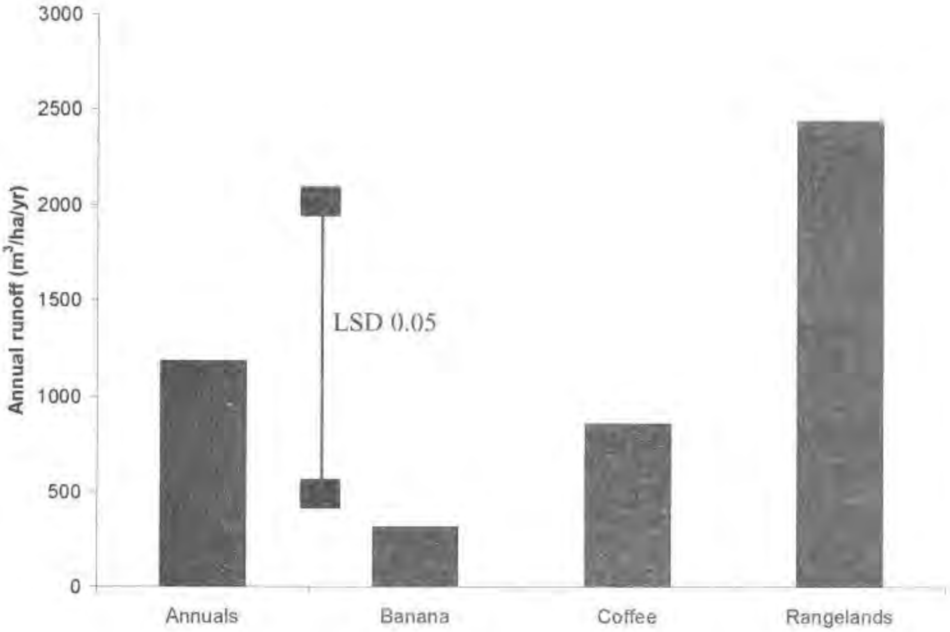

Figure 3: Average annual surface runoff from major agricultural land use types in the Lake Victoria basin (Mean of two years: 1998-1999)

Landuse dependence of both soil loss and runoff is attributed to local factors such as topography, canopy cover, groundcover, and soil properties. Banana and coffee are grown on pediments with gentle slopes, while annuals and rangelands are on hill tops and relatively steepslopes (Ssali and Isabirye, 1998). Moreover, banana and coffee present a relatively constant good canopy cover compared to annuals, where the land is bare at the time of planting.

Soil loss recorded in this study is in a similar range as that recorded by other researchers in the Lake Victoria basin (Zake and Nkwiine, 1995; Tukahirwa, 1996, Majaliwa, 1998), especially for banana, coffee and annuals. This confirms the relatively high aggressivity of rains in the Lake Victoria basin. Data on seasonal soil loss and runoff from major agricultural land-use types are presented in Table I and II. Seasonal soil and runoff losses have similar pattern as annual soil ($p=0.031$) and runoff losses ($p=0.022$). Seasonal soil loss significantly contributed to the annual soil loss ($p<0.05$), and account for more than three quarters of the annual soil loss for all major agricultural land-use types. This was only true for banana and rangelands concerning runoff ($p<0.05$). Non seasonal runoff losses were not significantly different to seasonal ones for coffee and annuals. This is attributable to the states of these lands during that period and climatic fluctuations.

Table I: Seasonal soil loss from major agricultural land-use types in the Lake Victoria catchment

Land-Use	Soil loss (t/ha)				Seasonal/annual
	Seasons				%
	98A	98B	99A	99B	
Annuals	103.18	23.75	9.08	28.17	82.2
Unmulched Banana	10.12	8.86	6.85	29.48	97.5
Mulched Banana	27.70	8.63	2.86	13.78	88.6
Coffee	8.54	9.79	8.36	19.62	85.2
Rangelands	34.24	11.79	11.73	31.48	76.9
LSD between Landuse					
LSD between year					

Table II: Seasonal runoff (m^3 /ha) loss from major agricultural land-use types in the Lake Victoria catchment (Mean of two years : 1998-1999)

Land-Use	Runoff				Seasonal/annual
	Seasons				%
	98A	98B	99A	99B	
Annuals	529.24	58.69	828.13	635.19	68.95
Unmulched Banana	14.98	37.34	167.48	413.78	89.82
Mulched Banana	89.29	23.23	185.68	602.24	87.56
Coffee	28.12	83.05	621.05	406.19	66.24
Rangelands	934.08	167.62	1433.96	2506.61	89.48
LSD between Landuse				376.00	
LSD between year				238.00	

LSD : Least significant difference

However, though high soil loss from annuals and high runoff loss on degraded rangeland were expected, a similarity in soil loss is suprising. It seems suprizing also that banana and coffee had a similar amount of soil loss and runoff. The magnitude of soil loss on degraded rangeland can be associated to the soil type difference in rangelands (Ssali and Isabirye, 1998); the non difference in soil and runoff losses on coffee and banana could be attributed to management variations on banana gardens as illustrated by Table I and II, depicting seasonal soil and runoff losses.

Soil nutrient losses

Selected chemical properties of the sites for the different land-use types at the beginning of the study (1998) and two years later (2000) are presented in Table III and IV.

Table III: Selected chemical properties of soil under different land-use systems at the start of the experiment (0-30 cm) (n=2), August 1998

Landuse	pH	OM %	N %	P --	K mg/kg	Na	Ca -- --	Sand --	Clay %	Silt --
Annuals	5.6	7.80	Na	129.80	12.57	1.40	78.05	33.8	23.6	42.6
Banana	5.5	4.30	Na	739.23	37.94	5.74	241.83	49.8	29.6	20.6
Coffee	5.2	4.20	Na	12.99	6.11	0.56	52.83	35.8	30.0	34.2
Rangelands	4.5	8.60	Na	4.28	9.43	2.47	53.54	37.8	56.0	6.2

Table IV: Selected chemical properties of soil under different land-use systems (Average 0-15 and 15-30 cm), July 2000

Landuse	pH	OM %	N %	P --	K mg/kg	Na --	Ca --	Sand --	Clay %	Silt --
Annuals	5.45	7.97	0.34	399.00	29.80	6.62	77.00	34.10	31.80	34.13
Banana	6.97	5.73	0.28	337.00	47.40	9.92	111.20	42.00	29.60	28.30
Coffee	5.47	6.62	0.27	10.00	34.30	7.11	92.60	33.30	35.60	31.07
Rangelands	5.10	7.66	0.22	136.00	20.40	3.41	53.80	34.10	33.40	32.58
Lsd (0.05)	0.38	1.19	0.07	281.60	11.87	2.74	33.80	6.95	2.47	5.39

Nutrient concentrations of eroded sediment (seasonal) from major agricultural land-use types are summarized in Table V.

Eroded sediments had relatively high nutrient concentrations than the remaining soils, as illustrated by Table IV, and varied with land-use and /or seasons ($p<0.05$). Available P and K remained independent of both land-use type, and

Table V: Selected nutrient concentration of eroded sediment from major agricultural land- use types in Lake Victoria catchment (1999-2000)

Period of the year	Land-use	OM %	N %	P --	K mg/kg	Ca --	Na --
Long rains 1999	Annuals	4.59	0.36	303.00	63.67	238.94	113.11
	Banana unmulched	4.77	0.34	339.00	79.04	246.09	6.70
	Banana Mulched	9.07	0.35	429.00	108.04	290.09	13.70
	Coffee	6.23	0.39	99.00	35.67	223.33	5.67
	Range lands	4.03	0.28	384.00	29.00	32.00	3.00
Short rains 1999	Annuals	5.64	0.32	198.00	30.52	65.21	10.81
	Banana unmulched	6.26	0.28	184.00	3.13	40.24	7.77
	Banana Mulched	7.31	0.44	26.00	209.12	501.33	40.53
	Coffee	8.45	0.38	413.00	19.50	570.77	27.03
	Rangelands	7.97	0.24	668.00	347.33	164.67	178.33
Long rains 2000	Annuals	9.80	0.29	400.00	71.67	147.33	223.00
	Banana unmulched	4.78	0.16	149.00	66.39	240.81	172.72
	Banana Mulched	8.03	0.30	177.00	88.39	260.31	271.72
	Coffee	8.90	0.38	213.00	60.00	132.67	231.67
	Rangelands	6.42	0.26	729.00	169.00	279.00	200.00
Short rains 2000	Annuals	10.50	0.34	375.00	160.33	204.33	99.08
	Banana unmulched	6.92	0.23	218.00	154.78	904.80	158.25
	Banana Mulched	7.52	0.32	34.00	56.55	303.79	298.54
	Coffee	8.17	0.30	204.00	86.67	156.00	253.01
	Rangelands	10.00	0.37	469.00	141.17	242.08	375.30
LSD0.05							
Across years		1.00	Ns	Ns	Ns	37.8	37.8
Between seasons		Ns	Ns	Ns	45.5	37.8	46.3
Landuse		1.58	ns	162.4	72.0	Ns	37.8

season ($p<0.05$), N changed with season, while OM varied with land-use type ($p<0.05$). For N the long rains sediments contained more N than the short rains for both banana unmulched and grazing land ($p<0.05$). OM was highest under grazing land, followed by mulched banana, annuals and unmulched banana, and then coffee during the long rains ($p<0.05$). For the short rains, the highest OM content was observed on mulched banana and coffee, followed by grazing land, annuals and last unmulched banana ($p<0.05$).

The total nutrient losses one-year before and after establishment of contour bunds are presented in Figure 3-5. The total amount of OM loss through eroded sediment varied between 430 and 5200 kg/ha. Total amount of available P loss varied between 0.82 and 12 kg/ha. The amount of total N loss ranged between 15.30 and 157.64 kg/ha. Total amount of K ranged between 0.21 and 7.3 kg/ha. The amount of nutrient (N,P, and K) and OM loss from agricultural land through surface runoff varied with seasons ($p<0.05$). The highest loss of nutrient occurred during the short rains season ($p<0.05$). This was true for coffee and grazing land for K ($p=0.009$), annuals, unmulched banana, coffee and grazing land for N ($p=0.013$), annuals, coffee, and grazing land for OM ($p=0.001$), and unmulched banana for P ($p=0.021$). Nutrient losses through water erosion in the catchment are extremely high. It reinforces prediction by Stoorvogel and Smaling (1990) and IFDC (1999) on nutrient depletion in Uganda.

Effect of contour bunds soil nutrient losses

Nutrient concentrations after establishment of contour bunds are presented in Figure 2, 3, 4, 5 and 6. After establishment of contour bunds, significant changes in soil nutrient concentrations were observed for OM, Ca and Na ($p<0.05$). OM, Ca and Na concentrations on rangelands, and concentration of Ca on coffee increased for both seasons. Concentration of Na increased for all major agricultural land-use types for both seasons. Eroded sediment from annuals had opposite seasonal trends. It relatively increased during the short rains. N, available P and K concentration in eroded sediments did not change with establishment of contour bunds ($p<0.05$).

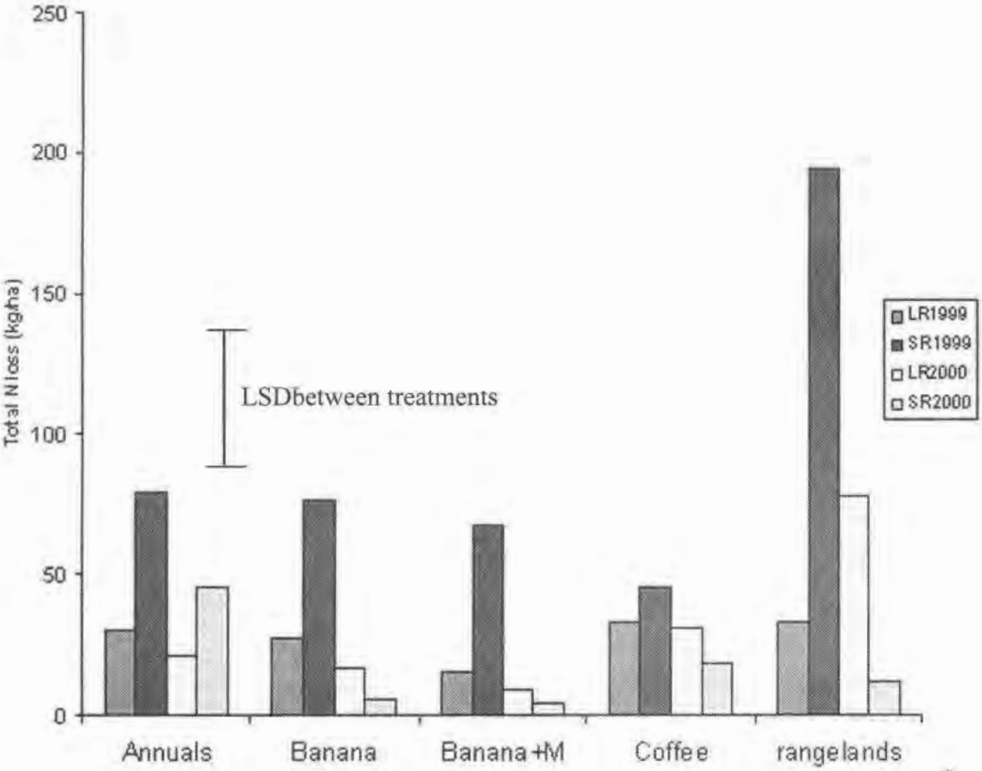

Figure 4. Amount of Total N loss from the major agricultural land use types in Lake Victoria catchment. (Banana: unmulched banana, Banana+M: Mulched banana)

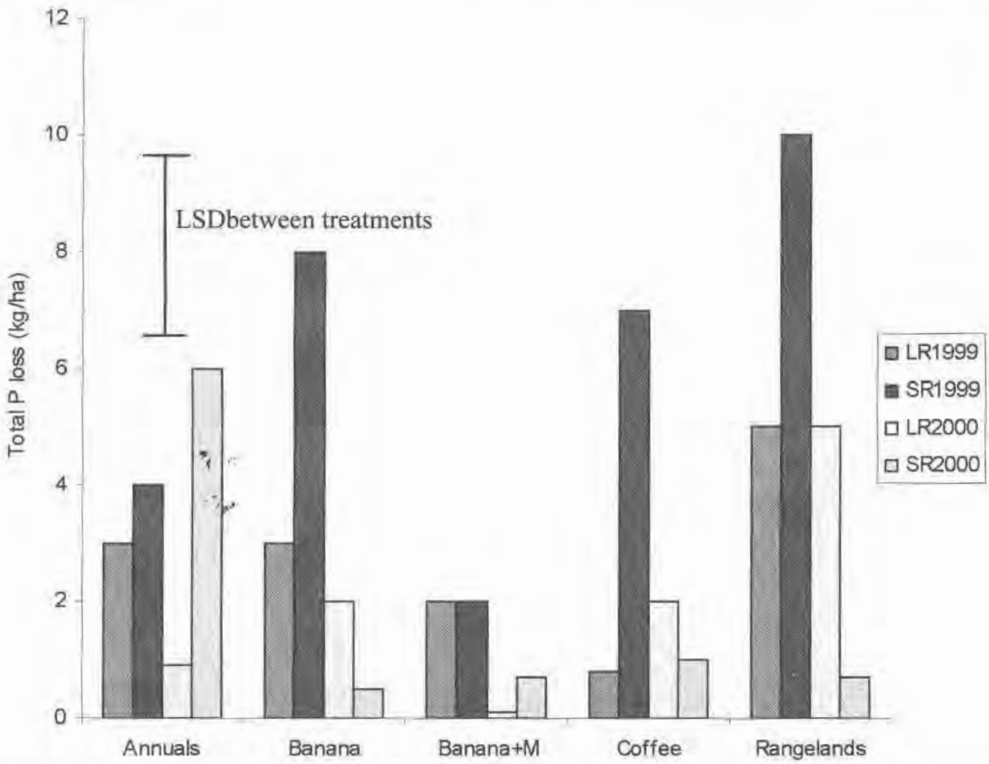

Figure 5. Amount of available P loss from the major agricultural land-use types in Lake Victoria catchment

The total amount of nutrient loss one-year after establishment of contour bunds showed seasonal variability ($p<0.05$). The amount of total N ranged from 3.84 to 78.26 kg/ha/season, available P ranged between 0.1 and 6 kg/ha/season, and available K ranged between 0.13 and 3 kg/ha/season. Only the amount of OM, available P, and total N and Na losses changed after establishment of contour bunds. The amount of Total N loss decreased for all major agricultural land-use types except rangelands, where it increased instead. During the short rains the amount of available P loss decreased on unmulched banana, coffee and rangeland only.

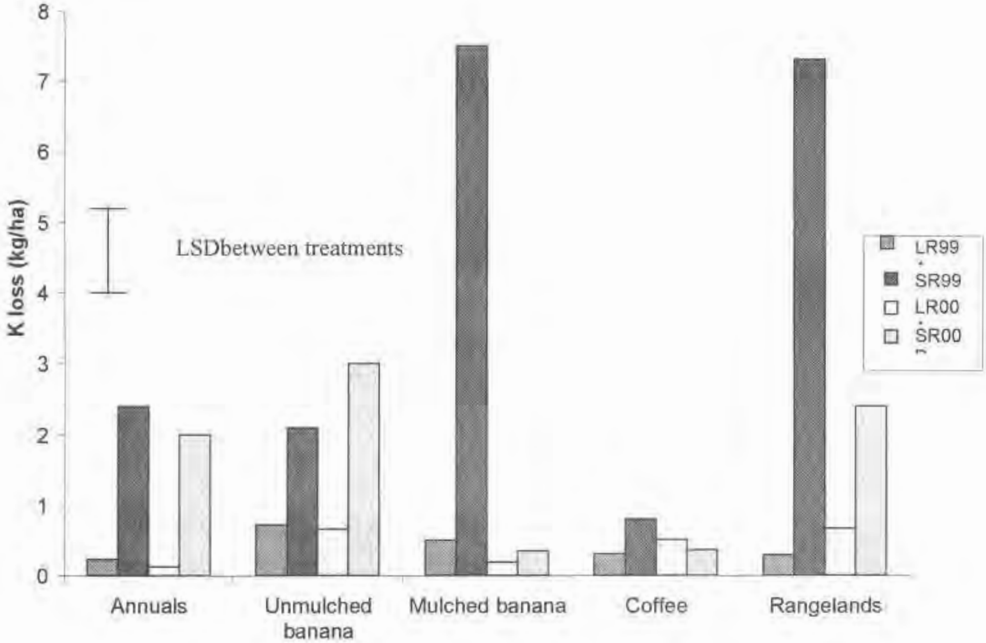

Figure 6. Amount of available K loss from the major agricultural land-use types in the Lake Victoria catchment

The amount of exchangeable Na loss increased on unmulched banana, coffee and rangeland. The amount of available K loss decreased on annuals, mulched banana and rangelands for the short rains only. However, the amount of total N, available P, and available K losses through surface runoff were still substantial. The observed reduction of nutrient losses is a consequence of soil loss decline due to the establishment of contour bunds.

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that water erosion induced soil nutrient losses continuously degrade lands in the catchment. It also establishes that nutrient losses are land-use type dependent, and are cut down by contour bunds through soil erosion control. However, a long-term trend is needed in order to establish the effect of contour bunds on the total loss of nutrients from different land-use type within the catchment. There is also need to correlate soil nutrient depositions in the basin to establish water enrichment that is due to agricultural practices.

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