Soil and nutrient losses from major agricultural land-use practices in the Lake Victoria basin

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Abstract

Soil degradation by water erosion is recognized to be a major agricultural and environmental problem in the Lake Victoria crescent. The objective of this study was to quantify runoff, soil and nutrient losses from major agricultural land use practices and assess the efficiency of contour bunds in controlling the tide of those nutrient losses in two selected micro-catchments of the Lake Victoria Basin. The experiment was conducted on thirteen-instrumented runoff plots, measuring 15m by 10 m, established on farmer's fields on banana, coffee, annuals and degraded rangelands. Each of the four land-use practices was replicated three times, except banana, which was replicated four times. Two plots under banana were mulched and two were not. Contour bunds were hand-constructed two years after runoff plots establishment. Eroded sediments were collected, aggregated per season and analysed for selected nutrients. The average annual runoff ranged between 315.47 and 2438.92 m^3 ha^{-1} yr^{-1}. Degraded rangelands lost relatively higher amounts of rainfall water through surface runoff compared to banana and coffee (p=0.022). The average annual soil loss ranged from 27.7 to 86.7 t ha^{-1} yr^{-1}. It was higher on annuals compared to banana and coffee (p=0.038). Eroded sediments had relatively high nutrient concentrations than the remaining soils, and varied with land-use and /or seasons ($p<0.05$), and did not show a single pattern for all nutrients. The amount of nutrient loss through erosion was relatively high, and varied with seasons for N,P, K and OM ($p<0.05$). Establishment of contour bunds led to an increased OM and Ca and Na content in eroded sediments, while total OM and TN losses decreased for all practices except rangelands where they increased. TNa increased on coffee, rangelands and mulched banana ($p<0.05$). TP and TK losses decreased only on annuals, mulched banana and rangelands for the short rains ($p<0.05$). These exports from agricultural land play a major role in the nutrient enrichment of rivers and open water bodies.

Keywords: Pollution, sustainability, farming system, land-use

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, *et al*., 1982; Aid, 1988; Lal, 1989; Oldeman *et al.,* 1990; Sanders, 1992; Stocking, 1995; Magunda and Tenya, 1998). In Uganda, soil loss rates recorded in different locations are higher than the tolerable values (Bagoora, 1990; Majaliwa, 1998) and have 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 degrades vegetation cover (Mokwunya, 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 is commonly loaded with relatively rich soil nutrients. The removal of nutrient enriched soil from cropland leads to the per capita food production decline (Dunne and Dietrich, 1982; Pieri, 1989; Sanchez, 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.,* 1997). The net result of the on-going degradation may culminate in a vicious circle of low income, low input and low yield (GTZ, 1995; Crosson, 1995).

Part of the runoff and sediments generated from different land-uses including croplands always ends up in drainage networks. The Lake Victoria and its tributaries are already showing signs of enrichment (Hecky, 1993). Past surveys on eutrophication and pollution pinpoint agricultural land as proximate cause of the on going degradation in the water bodies (Edwards and Blackie, 1981; Chebeda, 1983). In the catchment, the key for sustainable use of resources is the identification of effective pollutant areas, quantification of nutrient flows from different land-use practices and identification of possible successful mitigating measures.

Best management practices (BMP) represent a wide range of widely used technical opportunities that 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 increasing infiltration and reducing runoff. As a consequence erosion and sedimentation are expected to be reduced with attendant impact on the aquatic ecosystem, up and down stream characteristics and adjacent land features. 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 effect of contour bunds on the nutrient losses.

Materials and methods

The experiments were conducted in Kifamba sub-county, Rakai District, located between 0° 35' - 1° 00' S and 31° 15' - 31° 48' N. Sixty six percent of the district is in Bukora sub-catchment of the Lake Victoria basin. The climate is characterised by a bimodal rainfall regime where 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 and the mean monthly temperature is 23 °C. The sub-catchment is drained by river Kibale, a major influent tributary to Lake Victoria. 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, as grazing, forestry, and mixed-cropping.

Thirteen runoff plots measuring 15 by 10 m were established, during 1998A, on farmers' fields, representing four major agricultural land-use practices, namely: annuals, banana, coffee and degraded rangelands. The runoff plots were managed by farmers. Each agricultural land-use practice was replicated three times except banana, which was replicated four times with two plots mulched and two unmulched. The slope of runoff plots ranged between 14 and 15% for coffee and banana, and 29 and 49 % for rangelands and annual crops. 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 analysed for nutrient concentration. Two years after establishment of runoff plots contour bunds were hand-constructed at a spacing of 20 m along the slope where runoff plots were sited and nutrient losses were monitored for one year. Soils were sampled at the beginning of the experiment and three years after (depth of 0-30 cm), and then analysed also for routine nutrient contents (Foster, *op. cit.*). The total nutrient loss per agricultural land-use practice 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 estimated 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 practices of the Lake Victoria catchment are presented in Figures 1 and 2.

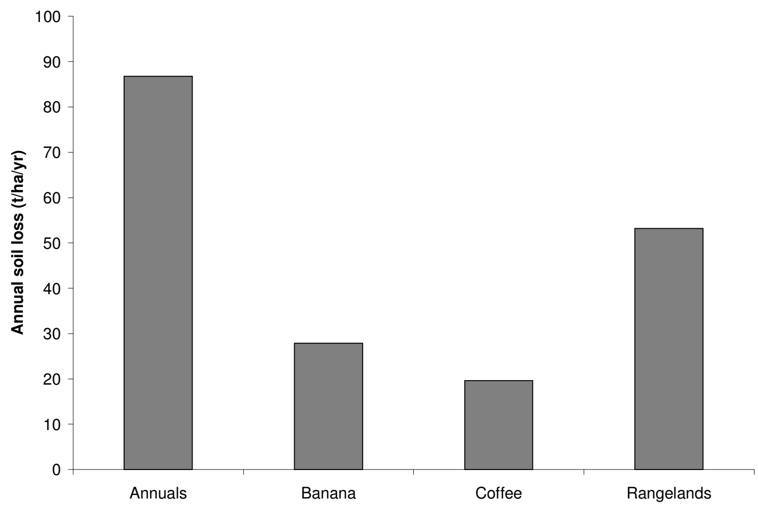

Figure 1. Average annual soil loss from major agricultural landuse practices in the Lake Victoria Basin. (average of two years 1998-99)

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 rangelands lost relatively higher amount of rainfall water through surface runoff compared to banana and coffee (p=0.022). Surface runoff represented 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.

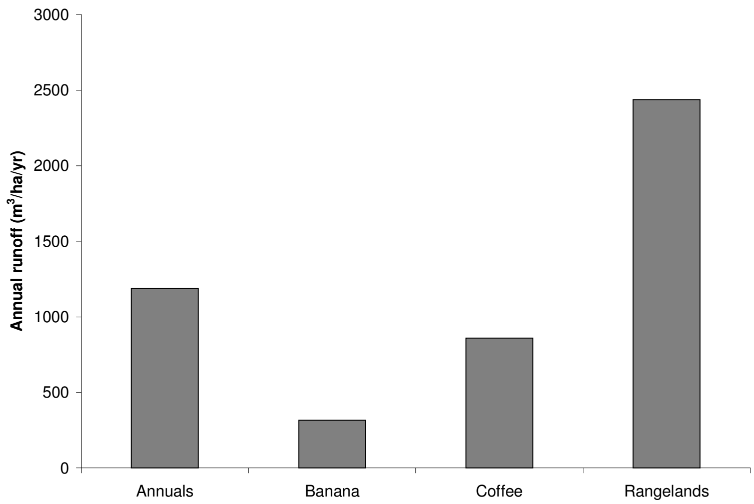

Figure 2. Average annual surface runoff from major agricultural landuse practices of the Lake Victoria basin

The dependence of both soil loss and runoff d on landuse 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 hilltops and relatively steep slopes (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 crescent. Data on seasonal soil loss and runoff from major agricultural land-use practices are presented in Table 1 and 2. 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 quarter of the annual soil loss for all major agricultural land-use practices. This is only true for banana and rangelands runoff ($p<0.05$). Non-seasonal runoff losses were not significantly different from seasonal ones for coffee and annuals. This was attributable to the states of these lands during that period and the experienced climatic fluctuations.

Table 1. Seasonal soil loss (t/ha) from major agricultural land-use practices in the Lake Victoria catchment units

Landuse	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
LSDlanduse	376.				
LSDyear	238				

Table 2. Seasonal runoff (m^3/ha) from major agricultural land-use practices in the Lake Victoria catchment

Landuse	Soil loss (t/ha)				Seasonal/Annual
	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
LSDlanduse	14.64				
LSDyear	9.26				

However, though high soil loss from annuals and high runoff loss on degraded rangelands were expected, their similarity in soil loss is surprising. It seems surprising also that banana and coffee had similar amount of soil loss and runoff. The magnitude of soil loss on degraded rangeland can be associated with the soil type difference in pastureland (Ssali and Isabirye, 1998); the similarity in soil and runoff losses on coffee and banana could be attributed to management variations on banana gardens.

Soil nutrient losses

Selected chemical properties of the sites for the different land-use practices at the beginning of the study (1998) and two years later (2000) are presented in Tables 3 and 4. Nutrient concentrations of eroded sediment (seasonal) from major agricultural land-use practices are summarized in Table 5.

Eroded sediments had relatively high nutrient concentrations than the remaining soils, as illustrated by Table 3, 4 and 5, and varied with land-use and /or seasons ($p<0.05$). Available P and K remained independent of both land-use practice type, and season ($p<0.05$), N changed with season, while OM varied with land-use practice ($p<0.05$). For N the long rains sediments contained more N than the short rains for both unmulched banana 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 Figures 3 to 5. The total OM loss through eroded sediment varied between 430 and 5200 kg/ha. Total available P loss varied between 0.82 and 12 kg/ha. The total N loss ranged between 15.30 and 157.64 kg/ha. Total 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 ($p=0.021$).

Table 3. Selected chemical properties of soil under different land-use systems at the start of the experiment (0-30 cm) (n=2), 1998

Landuse	pH	OM %	N %	(P	K Mg/g^{-1}	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 4. Selected chemical properties of soil under different land-use systems (0-30 cm), July 2000

Landuse	pH	OM %	N %	P	K Mg/kg^{-1}	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	0.38	1.19	0.07	281.60	11.87	2.74	33.80	6.95	2.47	5.39

Table 5. Selected nutrient concentration of eroded sediment from major agricultural land-use practices 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	163.67	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

Nutrient losses through water erosion in the catchment are extremely high. It reinforces prediction by Stoovogel and Smaling (1990) and FAO (1989 cited by IFDC, 1999) on nutrient depletion in Uganda.

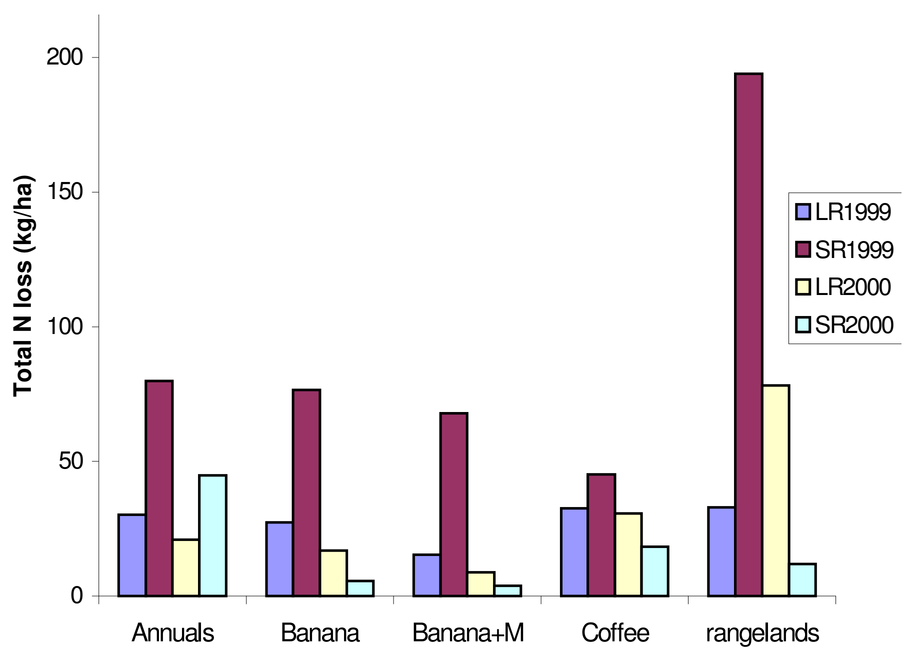

Figure 3. Total N loss from the major agricultural land practices in Lake Victoria basin

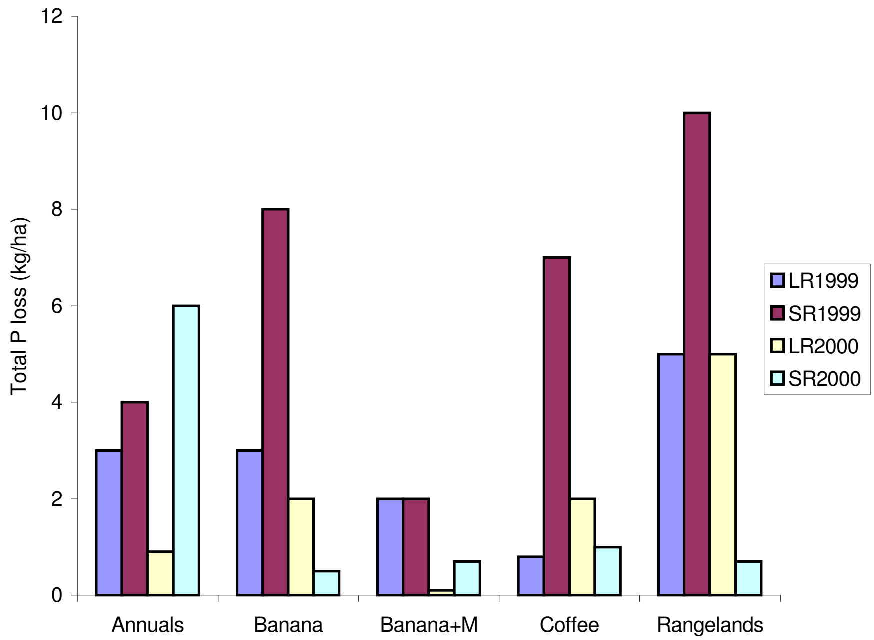

Figure 4. Total available P from the major agricultural landuse practices in Lake Victoria Basin

Effect of contour bunds on soil nutrient losses

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 practices for both seasons. Eroded sediment from annuals had different seasonal trends. Na increased during the short rains. N, available P and K concentration in eroded sediments did not change with establishment of contour bunds ($p<0.05$). Perhaps the long drought could have contributed to the increase in Ca and Na.

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

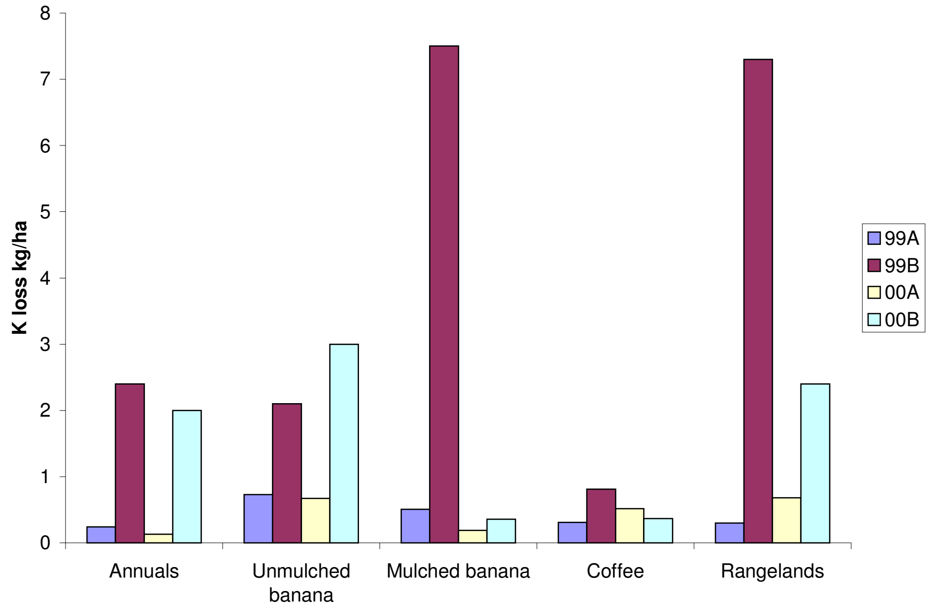

Figure 5. Total K loss from the major agricultural land-use practices in Lake Victoria Basin

Conclusion

Soil loss in the Lake Victoria Basin is higher than the tolerable value. Higher losses occur on annuals for soil and rangelands for runoff. This study demonstrates that lands are continuously degraded by water erosion and relatively high losses of nutrients occur on agricultural land in the catchment. It also establishes that nutrient losses are land-use practice dependent, and are considerably reduced by construction of contour bunds. 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 practices 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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