International Scholars Journals

International Journal of Agricultural Sciences ISSN 2167-0447 Vol. 5 (6), pp. 854-863, August, 2015. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Efficiency of contour bunds in controlling soil and nutrient losses from major agricultural land-use types in the Lake Victoria Catchment

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Accepted 28 July, 2015

This study determined the efficiency of contour bunds in controlling soil and nutrient losses from annual crops, bananas, coffee, and rangelands in the Lake Victoria catchment. Soil and nutrient losses were quantified using a runoff plot approach. Runoff plots measuring 15 m x 10 m were established on each agricultural land-use and were replicated four times for banana and three times for annual crops, coffee and rangelands.. Runoff data was collected for one year prior to the establishment of contour bunds. The bunds were hand constructed 5 m above each plots, and data was thereafter collected for three years. Soil and nutrient losses were significantly higher on annuals compared to other land-uses (P<0.05). Contour bunds efficiency in controlling soil loss increased linearly with time on all land-uses (P<0.05); while for runoff losses it gradually increased only for coffee and rangelands (P<0.05). For nutrient loss the contour bunds efficiency varied with the type of nutrient and land-use type.

Key words: Soil erosion, water pollution, Lake Victoria, nutrient transfers, Uganda.

INTRODUCTION

Conversion of forest into agriculture and urban areas with subsequent alteration of stream patterns and quality, represents the widespread threat to the health of many ecosystems in the world today (Chittleborough, 1983; Carpenter et al, 1998; Johnes and Burt, 1991, Boughton *et al.*, 1997; Barbash *et al.*, 1999; Bricker *et al.*, 1999; Bunn et al., 1999; Goolsby *et al.*, 1999; Litke, 1999; McGlathery *et al.*, 2000; Lambin *et al.*, 2001; Howarth and Morino, 2006; Groffman *et al.*, 2004). For many tropical ecosystems, land-use/cover change is a result of population pressure on the resource for agricultural production (McConnell *et al.*, 2004; Walker, 2001). Consequently, soils become highly eroded and degraded. In the Lake Victoria catchment, several studies have confirmed that soil erosion is severe under some environments and particularly on agricultural lands (Mulebeke,

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2010). Several studies have pointed out agricultural activities as the main cause of the ongoing degradation of Lake Victoria and its tributaries (Chabeda, 1983; Zake, 1995; Gachene, 1998; Lufafa *et al.*, 1999; Geoghegan *et al.*, 1998; Magunda and Majaliwa, 2002; Majaliwa *et al.*, 2004).

Watershed studies conducted in selected Lake Victoria catchment suggest that sediments and runoff partial contributing areas represent about 20% of the catchment area (Majaliwa *et al.*, 2004). Excessive transport of pollutants from these agricultural lands is attributed to the types of soil, rough topography, inadequate vegetation cover on cultivated lands, very aggressive climate, and poor management of land resources (Thomas *et al.*, 1992; Zake, 1995; Tenywa *et al.*, 1999; Magunda and Majaliwa, 2002; Kyarisiima *et al.*, 2008). In the Lake Victoria catchment, agricultural practices are mainly at subsistence level and have evolved over the years through trial and errors by farmers to meet their daily demands of food, fodder, fuelwood and timber (Bekunda and Woomer, 1996; Geist and Lambin, 2002; Tenywa *et al.*, 1999; Sullivan, 2003). Considering the limited resources of farmers, there are concerns whether the current extensification of agriculture and conversion of marginal areas to arable land are not likely to accelerate the export of sediments and associated nutrients into water bodies since the prevailing soil erosion rate is already far beyond the tolerable value (Johnes and Burt, 1991; Young *et al.*, 1996).

Increasing degradation of the water bodies and soils resources will reinforce the spiral of increasing poverty and land degradation unless effective strategies and practices to reverse the current trend are identified and implemented. A number of soil and water conservation interventions exist in the catchment but farmers are reluctant to adopt them, partly because the derived benefits are not known to them (Kyarisima *et al.*, 2008; Naagula and Buyinza, 2009; Mazvimavi and Twomlow, 2009). This study intended to determine the magnitude of soil, runoff and nutrient losses from major agricultural land-uses, and evaluate the trend in the efficiency of contour bunds to control soil, runoff, and nutrient losses from major agricultural land-uses in Bukoora micro-catchment in the Lake Vitoria Basin.

MATERIALS AND METHODS

The study was conducted in Rakai-District in Uganda, under the Lake Victoria Environmental Management Project (LVEMP). Rakai district is situated between 0^o 35' - 1^o 00' S and 31^o 15'- 31^o 48' E. The District covers an area of about 2,100 km^2. The climate is bimodal with annual precipitation ranging between 914 and 1,118 mm. The average temperature is 23^{o}C. The major soils in the area are ferralsols, gleysols and leptosols (Ssali and Isabirye, 1998).

Thirteen (13) instrumented runoff plots measuring 15 X 10 m each were installed on farmers' gardens in Kifamba sub-county, in Rakai district in Uganda. Three runoff plots were established under each major agricultural land-use type, except for banana, which was replicated four times and had two plots with mulch and two without mulch. All runoff plots were initially under farmers' management practices for two years. The farmer's practices involved hand weeding and land preparation was done using a hand hoe for annuals and banana, at the start of each season. In general, annual crops were intercropped with cassava,maize, and beans. The varieties planted were Longe 1 for maize and K131 for beans, "Mbwazirume" was the most dominant variety for bananas and coffee grown was of robusta type. The most dominant grass on selected ranges was *Brachiaria decumbens* (Abesiga *et al.*, 2001).

Runoff was monitored directly after each storm. One liter of composite runoff sample and a maximum of 100 g of eroded soil were collected after each storm. The composite runoff sample was oven dried at 105° C to determine the concentration of eroded sediment and the 100 g of soil was oven dried at 40 °C. Soil loss was computed by multiplying the concentration of sediments in the one-liter sample by the total runoff volume. The total soil and runoff losses during a given season were determined by summing up the different values obtained after each storm for the period covering that season (15th March-15th July for long rains, 1st September-31 December for short rains). The annual soil and runoff losses were computed as the sum of seasonal values.

To determine the seasonal concentrations of nutrients in eroded sediments, 75 g out of 100 g of the collected eroded materials for each storm were aggregated by seasons and land-use types, and were air-dried and analysed for available phosphorus (Av.P), potassium (K) and TN. Available phosphorus was extracted by Bray II method (Bray and Kurtz, 1945) and the exchangeable K+ was determined by a flame photometer. Average annual nutrient loss was computed as an average of seasonal values. Soil, runoff and nutrient data were entered into Microsoft excel and exported into Genstat 13th edition for statistical analysis (Lane and Payne, 1996). Mean values were computed and ANOVA for unbalanced experiments performed to separate the means. The efficiency of contour bunds on soil, runoff and nutrients was computed as a percentage relative change as compared to the year before the establishment of contour bunds.

RESULTS AND DISCUSSIONS

Magnitude of soil, runoff and nutrient losses under selected agricultural land-uses

Soil and runoff data generated from different agricultural land-uses for two rainy seasons for the years 1998-1999 is shown in Figure 1 and 2 respectively. The average annual soil and runoff losses from the four agricultural land-uses in the study area varied significantly ($p<0.05$). The average

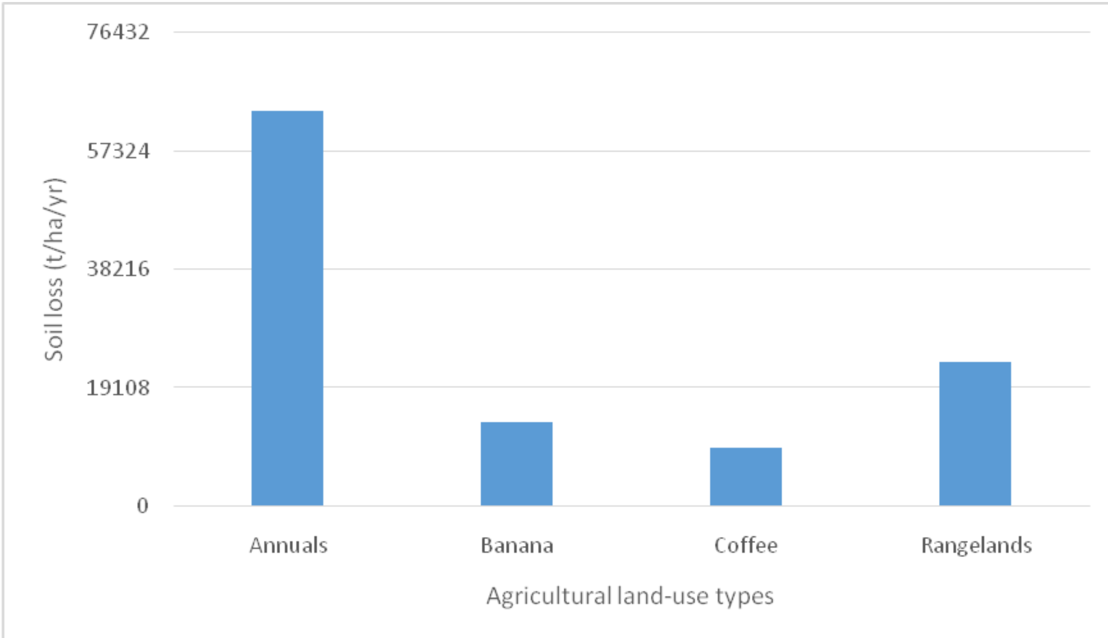

Figure 1. Soil loss from major agricultural land-use types in Bukoora sub-catchment under farmer management, Lake Victoria basin.

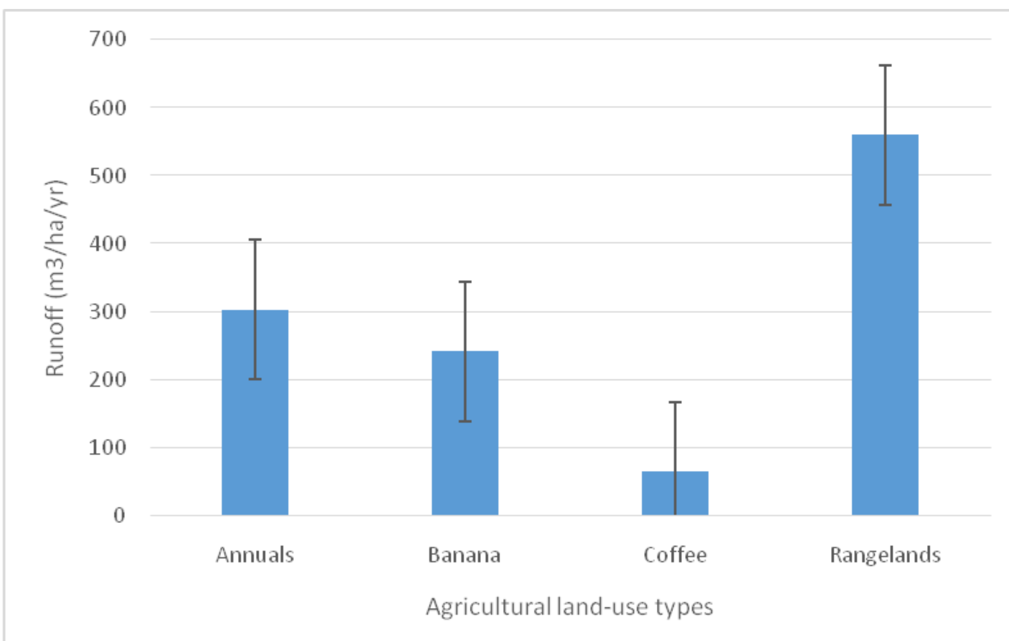

Figure 2. Runoff from major agricultural land-use types, in Bukoora sub-catchment, Lake Victoria basin.

annual soil loss ranged from 9.4 (Coffee) to 63.7 t/ha/yr (Annuals). Higher soil loss was recorded from annuals (63.7 t/ha/yr) compared to all the other major agricultural land-use types. Rangelands, banana and coffee had statistically similar values averaging 15.35 t/ha/yr.

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Average annual runoff generated from the major agricultural land-use types in Bukoora sub-catchment is presented in Figure 2. It decreased with land use type in the following order: rangeland (560.188 m^3/ha/yr), annuals (303.304 m^3/ha/yr), coffee (64.921 m^3/ha/yr) and banana (24.138 m^3/ha/yr). Rangelands generated significantly higher values of runoff compared to other agricultural land-use types (P=0.024).

Table 1 shows the concentration of nutrients before the introduction of contour bunds. Soil loss from annuals had relatively higher concentration of K compared to those observed from other agricultural land-use types (P<0.001). On average soil loss from annual crops had nine times more K content than the other three major agricultural land-use types. Total nitrogen ranged between 0.24 and 0.34% with the lowest value observed on soil lost from rangelands. The relatively lower TN content was observed in the soil loss from rangelands. Available phosphorus in soil lost varied between 79.9 and 316.6 mg/100g. The lowest available P content was observed in soil eroded from coffee gardens.

Table 2 shows the amount of av. P, extractable K and TN eroded from the different agricultural land-use types in Bukoora sub-catchment. The amount of av.P (194.58 Kg/ha/yr), extractable K (48.66 Kg/ha/yr) and TN (218.15 Kg/ha/yr) was the higher in soil lost from Annuals compared the other major agricultural land-use types (P<0.05). On average banana, coffee and rangelands lost 24.6; 2.5 and 37.5 Kg/ha/yr of Av.P, extractable K and TN; respectively.

Efficiency of contour bunds on soil, runoff and nutrient losses under selected agricultural land-use types

The trends in soil and runoff losses from major agricultural land–uses, after introduction of contour bunds, are given in the Figures 3 and 4 respectively. The efficiency of contour bunds in reducing soil loss increased linearly for all land-uses (P<0.05), and it tended to increase runoff for all land-uses except annuals where it remained quasi-constant. The coefficient of determination of the efficiency of contour bunds in controlling soil loss was highest for banana (0.88) followed by annuals (0.66), coffee (0.37) and then degraded rangelands (0.33). The gradient of the efficiency of contour bunds in controlling soil loss varied from 18.08% (coffee) to 31.20% (degraded rangelands). After three years soil loss from the four land-use types ranged between 5 and 10t/ha/yr.

The efficiency of contour bunds in controlling runoff tended to increase linearly with time on coffee, degraded rangelands and banana. However, it was statistically significant only for coffee (R^2= 0.74; P<0.05) and degraded rangelands (R^2=0.63; P<0.05). The efficiency of the controlling runoff remained quasi constant for the three years under annuals (R^2=0.0001, P>0.05) and banana (R^2=0.207, P>0.05).

In general, the concentration of nutrients in eroded sediments varied significantly across the years after the introduction of contour bunds (p<0.05). Figures 5, 6 and 7 show the trend of concentration of selected nutrients (available P, K and TN) in eroded sediments from major agricultural land-uses. The concentration of available P in eroded sediments did not vary significantly on annuals, banana and rangelands, but increased linearly on coffee (R^2=0.97, P=0.03). Though strong correlations were observed between av. P concentration and time since the introduction of contour bunds on banana and rangelands, the relationship was not significant (P>0.05).

Total nitrogen content in eroded sediments did not vary significantly with time (P>0.005), but tended to be lower on rangelands (P=0.06). It ranged between 0.32 and 0.347% for annuals, 0.23 and 0.31% on banana, 0.33 and 0.344% on coffee and 0.156 and 0.31% on rangelands.

Potassium concentration in eroded sediment varied significantly across the years. (P<0.001). It fluctuated under eroded sediments from annuals, increased exponentially on banana (R^2=0.62), coffee (R^2=0.80) and rangelands (R^2=0.79). Potassium content varied between 74.5 and 694.7 mg/100g for coffee, 26.7 and 1096.7 (mg/100g) for banana, 3.4 to 568.9 mg/100g for coffee and 11.3 to 1098.5 mg/100g for rangelands.

The efficiency of contour bunds in controlling nutrients loaded into lost sediments is shown in Figure 8, 9, 10 and 11; and depended on the type of nutrient. The efficiency of contour bunds to control the amount of K lost, remained quasi –constant for annuals, tended to decrease linearly under coffee (R^2=0.58), followed a quadratic shape for banana and degraded rangelands, with minimum efficiency reached after 2.69 and 2.74 years after the introduction of contour bunds for banana and degraded rangelands; respectively. The amount of P lost significantly varied with time (P<0.001) and agricultural land-use types (P<0.001). Generally the amount of P lost through eroded sediments declined with time and was higher under annuals compared to all the other agricultural land-use types. Strong correlation between contour bunds efficiency and time was observed for annuals (R^2=0.63), banana (R^2=0.52). It tended to follow a quadratic trend for coffee (R^2=0.49) with a minimum reached after 2.52 years after the introduction of the contour bunds. The efficiency of contour bunds on controlling P on rangelands increased exponentially (R^2=0.99, P=0.002).

DISCUSSION OF RESULTS

Magnitude of soil, runoff and nutrient losses

The magnitude of soil, runoff and nutrient losses in Bukoora sub-catchment under this study is in the range of values recorded by several authors (Majaliwa, 1998; Lufafa *et al.*, 2003; Mulebeke, 2010) in the Lake Victoria crescent. These values are generally moderate under perennial crops and grazing land and high to very high for annual crops (FAO, 1990). The values are also in the range recorded in Manafwa catchment in the Mt. Elgon

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Table 1. Nutrient content in eroded soils from major agricultural land-use types in Bukoora sub-catchment, Lake Victoria basin.

Agricultural land-use types	Av.P	K	TN
	mg/100g		%
Annuals	316.6^{a}	139.48^{a}	0.34^{a}
Banana	309.3^{a}	25.19^{b}	0.31^{ba}
Coffee	79.9^{b}	6.70^{b}	0.33^{a}
Rangelands	225.4^{ba}	14.13^{b}	0.24^{b}
Probability	0.02	<0.001	0.06

Table 2. Amount of nutrient eroded from major agricultural land-use types in Bukoora sub-catchment, Lake Victoria Basin.

Agricultural land-use types	P	K	TN
	Kg/ha/yr		
Annuals	194.58^{a}	48.66^{a}	218.15^{a}
Banana	24.76^{b}	2.18^{b}	26.35^{b}
Coffee	6.6^{b}	0.51^{b}	33.39^{b}
Rangelands	42.68^{b}	4.86^{b}	52.83^{b}
Probability	<0.001	<0.001	0.015

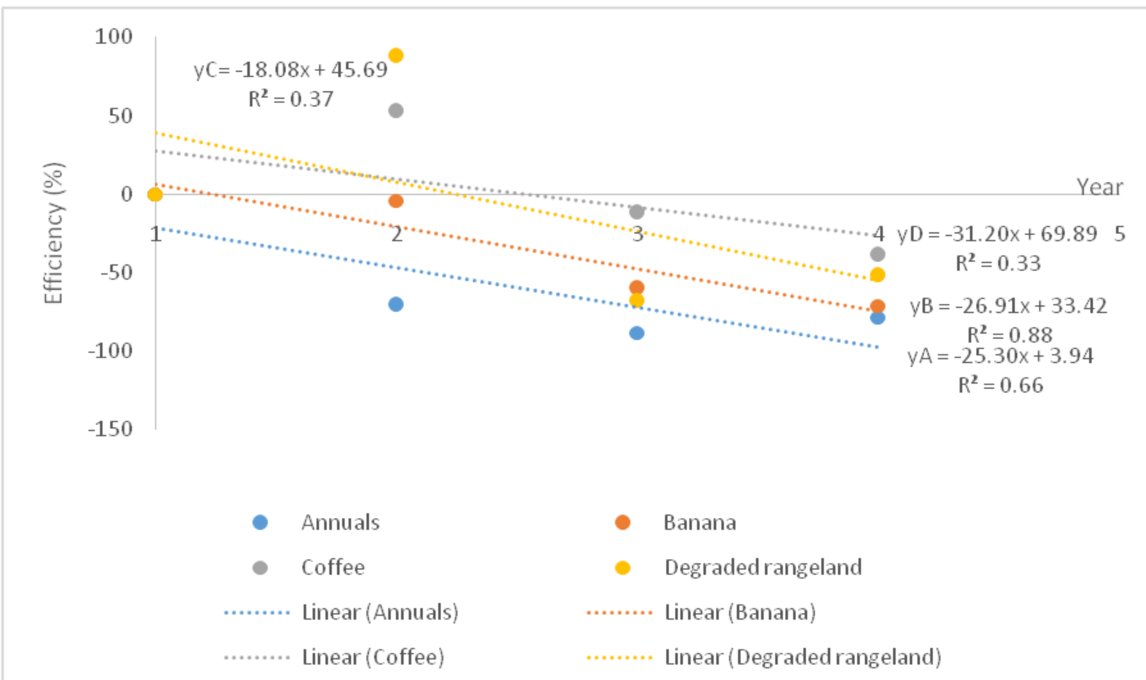

Figure 3. Efficiency of contour bunds in reducing soil loss from selected agricultural land-use in in Bukoora sub-catchment-Lake Victoria basin.

region for perennial crops (Bamutaze *et al.*, 2009). Variation in soil loss with agricultural land-use types is mainly due to their distribution along the landscape and their management. Generally in Bukoora sub-catchment perennials crops are mulched and are located on deep and highly weathered soil located on the foot slope (Bamutaze,*et al,* 2009; Majaliwa *et al*, 2015). The relatively high value of soil loss observed on annual crops in Bukoora sub-catchment is mainly attributed to the marginal nature of soils and the relatively high slope gradient of the locations where the annuals are grown.

Efficiency of contour bunds

The efficiency of contour bunds in controlling soil loss increased overtime, the trend depended on the agricultural land-use type. Contour bunds efficiency increased on banana and rangelands. Results from this study seem to contradict those of Roose (1966) and Hurni (1984) who observed that contour bunds were only effective on lower slopes. Reductions in soil and nutrients losses were attributed to the gradual improvement in soil physical properties, the relative increase in soil moisture, and increase in the canopy cover for rangelands (Wani et al., 2003). The role of contour bunds being that of cutting down the momentum of runoff water; allowing slow infiltration, and thus increasing the relative wetness of soils. Consequently, more loosely adsorbed cations such K, Na and Ca, which could have dissociated from the clay platelet could be made available in the soil solution as

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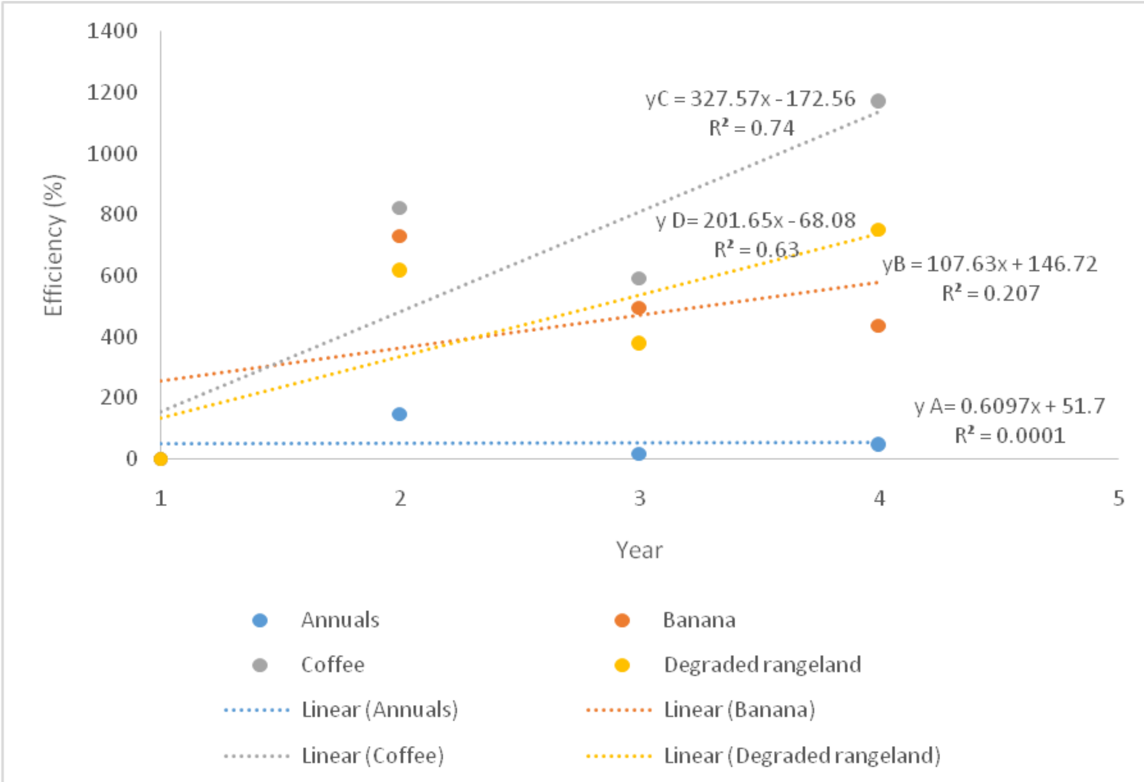

Figure 4. Efficiency of contour bunds in reducing runoff from selected agricultural land-use in Bukoora sub-catchment-Lake Victoria basin.

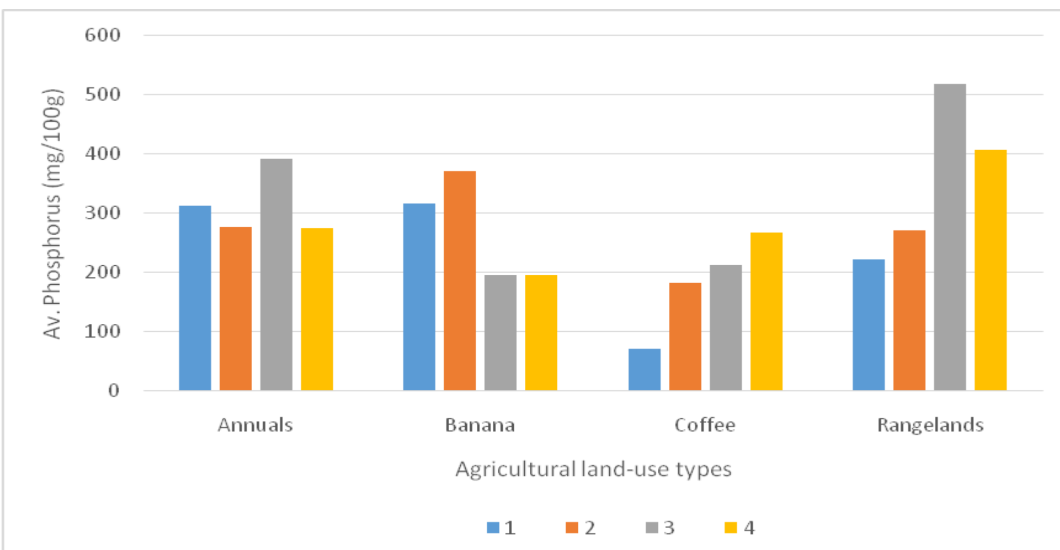

Figure 5. Available P content in eroded soil from major agricultural land-use types in Bukoora sub-catchment, Lake Victoria Basin.

moisture increases in the soils profile, and move with the infiltrated water laterally downslope. This can explain the increase of bases in soils with contour bunds (Majaliwa, 2004), and the relative increase in nutrient levels exported from them just after the introduction of contour bunds. Pathak et al., (2011) and Yair *et al.* (1978, 1980) had similar observations but attributed them to the increase in salinity when they were studying the partial contributing areas of

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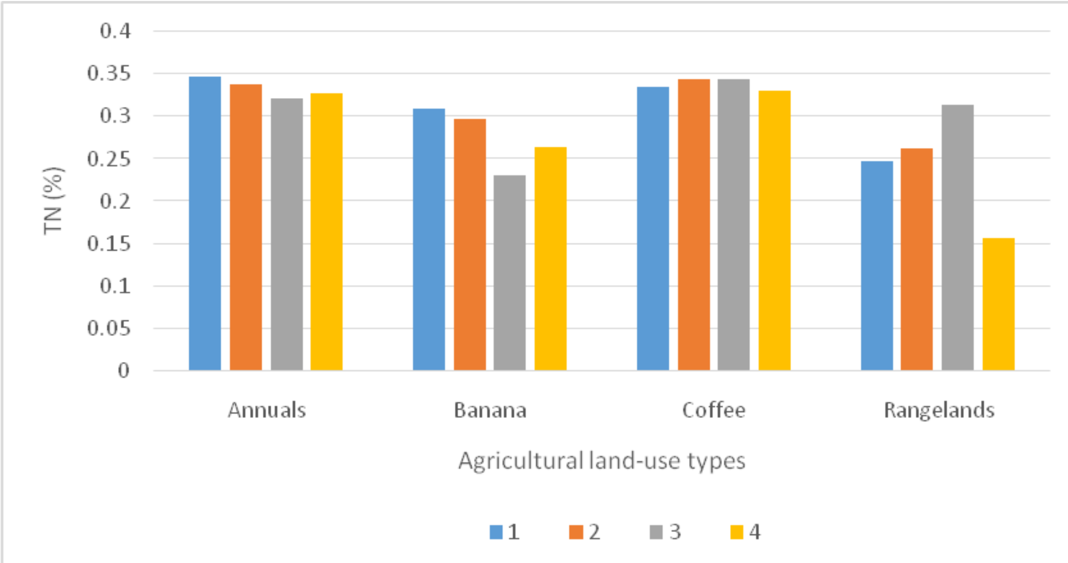

Figure 6. Total nitrogen content in eroded soil from major agricultural land-use types in Bukoora sub-catchment, Lake Victoria Basin.

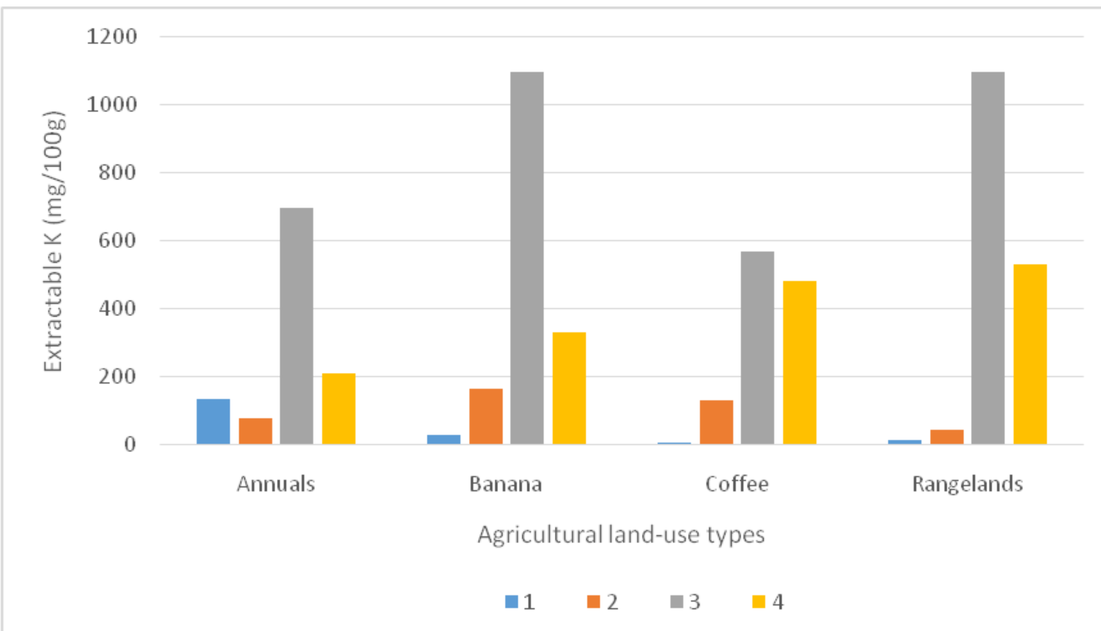

Figure 7. Extractable K content in eroded soil from major agricultural land-use types in Bukoora sub-catchment, Lake Victoria Basin.

Middle East watersheds. However, this can also be associated with the relative dryness of the area the year of the establishment of the experiments in 1999.

It is worthwhile to observe that on bananas mulch played a significant role in soil and runoff losses reduction. Research under both field and laboratory conditions have shown that the use of surface organic mulch results in storing more precipitation water in soil by reducing storm runoff, increasing infiltration, and decreasing evaporation (Bond and Willis, 1969; Unger, 1983; Schertz and Kemper, 1998). On ranges the relative reduction in soil loss and associated nutrient losses was attributed to the effect of ground cover improvement. Rangelands did not show any sign of improvement in infiltration characteristics; the sorptivity of soils under ranges was even reduced for the second year (Majaliwa *et al.*, 2004).

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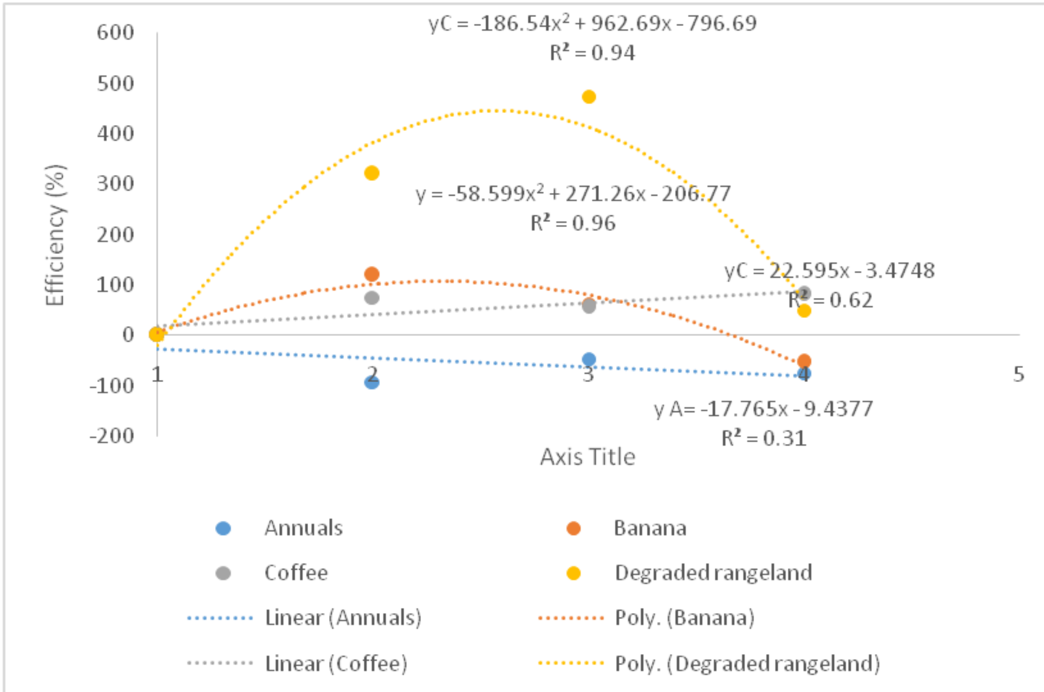

Figure 8. Efficiency of contour bunds in controlling the amount of Na lost for the selected agricultural land-uses in in Bukoora sub-catchment-Lake Victoria basin.

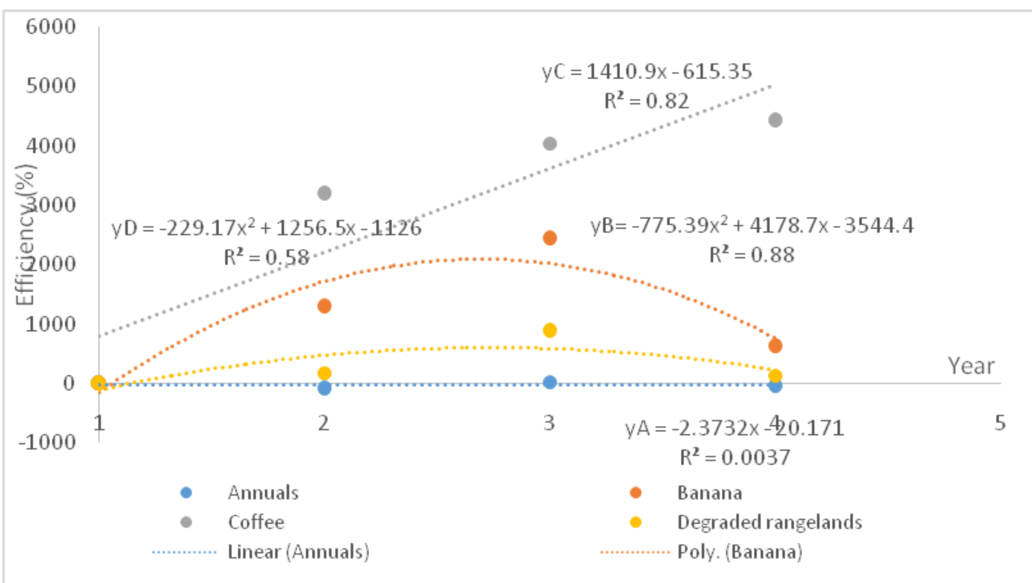

Figure 9. Efficiency of contour bunds in controlling the amount K lost for the selected agricultural land-uses in in Bukoora sub-catchment-Lake Victoria basin.

During that year, the farmer who managed two runoff plots, on ranges, had decided to graze more animals on the ridge where the runoff plots where located, because of their relative recovery. The relatively heavy grazing could have been responsible for the drop in sorptivity on rangelands. This elucidates the relative increase of available phosphorus on rangelands after establishment of contour bunds. High soluble P removal with runoff during the period of high grazing, and the role of sediment load in particulate P transport have also been confirmed by other researchers (Schuman *et al.*, 1973; Sharpley *et al.*, 1994).

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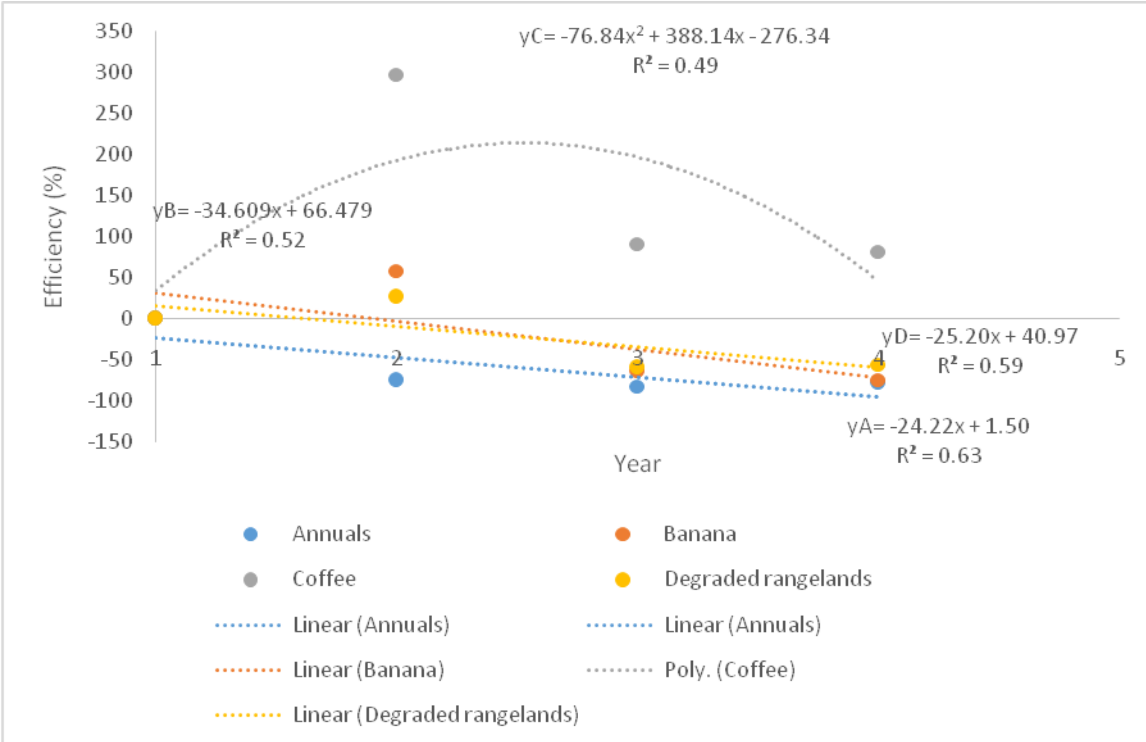

Figure 10. Efficiency of contour bunds in controlling the amount P lost for the selected agricultural land-uses in in Bukoora sub-catchment-Lake Victoria basin.

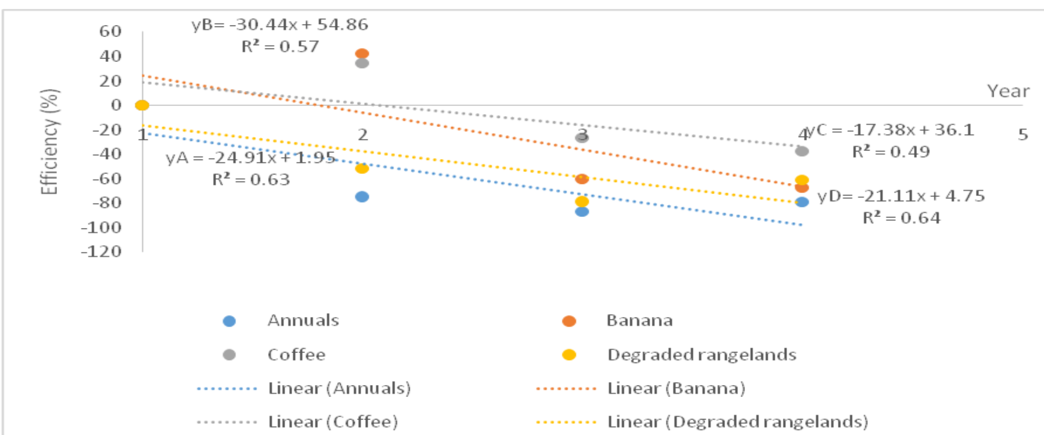

Figure 11. Efficiency of contour bunds in controlling the amount N lost for the selected agricultural land-uses in in Bukoora sub-catchment-Lake Victoria basin.

However, despite the soil structure improvement achieved runoff reduction was only significant on coffee and rangelands. This was attributed to the improvement in infiltration rate for the coffee and ground cover and biomass on rangelands (Majaliwa *et al.*, 2004b). The relatively high infiltration capacity characterizing the soils of the study area encourages rainfall of lower intensity to infiltrate. For banana the relatively high moisture content in soil was due to the presence of mulch and crop residues.

CONCLUSIONS AND RECOMMENDATIONS

Contour bunds were effective in controlling soil loss from the four major agricultural land-use types in the Lake Victoria basin. Contour bunds also controlled runoff for coffee and rangelands, and nutrient losses for coffee, banana and rangelands. In view of this performance, there is need of incorporating this land management technology in the set of soil erosion control measures to be implemented in the catchment. Moreover, an integration of contour bunds with an afforestation programme will accelerate the rehabilitation of degraded hillsides in Bukoora sub-catchment of the Lake Victoria basin.

ACKNOWLEDGEMENTS

This work was supported by the Global Environment Facility (GEF) and the Uganda Government through the Lake Victoria Environmental Management Project (LVEMP). I am grateful to all the field assistants who collected the valuable data.

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