Uganda Journal of Agricultural Sciences, 2003, 8 : 305 - 312 ISSN 1026-0919
Printed in Uganda

Soil erosion and pollution loading from agricultural land in Bukoora sub-catchment

[2]Majaliwa M.J.G, [1]Magunda M. K, [2]Tenywa M.M.,[1]Semalulu O.
[1] Kawanda Agricultural Research Institute (KARI) P.O. Box 7065 Kampala Uganda
[2] Makerere University, Dept. of Soil Science, P.O. Box 7062 Kampala Uganda

Abstract

High enrichment of eroded material in terms of fine particles and nutrients content is a result of the selective character of the erosion processes. The consequences are both on-site and off site and the concentration of fine particles and organic matter of eroded materials in water bodies leads to considerable pollution loads. The correlation between soil and nutrient exports agricultural land and suspended solid and nutrient loads in rivers of Bukoora sub-catchment in the Lake Victoria basin was determined. Soil and nutrient losses were measured from instrumented runoff plots. Thirteen instrumented runoff plots were established on banana, coffee, rangelands and annual crops. The distribution of different land-use types was mapped using 1: 120000 map and field transects. The coverage of the different land-use types was 10.5% (annuals); 17.1% (banana); 7.6% (coffee); 16%(banana-coffee); 11.8% (banana-annuals); 24%(rangelands), 1.9% (fallow); 3.2% (coffee-annuals); 7.5% (forest); and 0.4 % (bare land). Seasonal sediment, total available P, and total nitrogen export from agricultural land showed a very strong to moderate linear relationship with the corresponding parameter load at three hydrological stations. A similar pattern was observed between sediment export and total P and total N load. Generally, loadings from all the two micro-catchments were not highly correlated to the corresponding export parameters and sediment export from agricultural land compared to loads within the two micro-catchments. The pattern of correlation coefficient indicate that a lumped seasonal precipitation is not enough to model the export of sediment and associated loads in the two micro-catchments. Excessive nutrient losses by water erosion is a major soil degradation driving force leading to decreased production per unit area and hence increasing poverty.

Keywords: Nutrient exports, siltation, pollution loads, decreasing yields.

Introduction

The apparition of Water Hyacinth in the Lake Victoria in 1988 focused public attention on the deterioration of the quality of the water of one of the second largest surface water bodies of the world (Otieno, 1995). It was later established that the Lake was undergoing degradation since 1960, and that it has reached a more less advanced eutrophication status (Muggide, 1993; Lehman et al., 1993, Crul, 1995). Since then a good range of fish species, of unique cichild species, and other aquatic biodiversity has been lost or is in verge of extinction (Witte and Bouton, 1992 ; Otieno, 1995, Seehausen et al., 1997).

Increasing urbanisation, industrialisation and intensification of agriculture have been linked to the current status of the Lake Victoria and its tributaries (Calamari *et al.*, 1994). It is recognized, however, as for similar ecosystems in the world , that agriculture is the major contributor of the load (Raymond, 1984; Neely and Baker. 1989; Strebel et al., 1989; Power and Schepers, 1989; Rekolainen, 1993). Chabeda (1983) observed that Lake Victoria catchment rivers passing through forested lands were less nutrient enriched as compared to those crossing agricultural lands. In Bukoora, population pressure driven agriculture expansion, and poor land management and the geology of parent materials are proximite causes of the situation (Majaliwa et al., 2001).

The nutrients of interest are phosphorus and to a lesser extent, nitrogen (Harris, 1992; Kaupi, 1993; Sharpley *et al.,* 1995a; 1995b). Most of P and N are transported from agricultural land to the water bodies mainly during the growing seasons (Casey, 1990). Very recent studies *in the* sub-catchment revealed the existence of three peak loads of pollutants at the beginning and the end of growing seasons (Semalulu, 2001). It is possible that the two micro-catchments response factor, intensive rains after a relatively dry period may have played a significant role in these temporal peak loads. However, this brings forward the problem of partitioning of the load, and the portion contributed by agricultural land in the actual loads. The aim of this study was to correlate sediment and nutrient exported from land surface to the corresponding parameters observed in the major tributaries of Bukoora sub-catchment.

Materials and Methods

The study sites and experimental set up design were described elsewhere (Magunda et al. 1999). The study sites are located in Kakuuto – Rakai district. The rainfall is bimodal with annual precipitation ranging between 914 and 1118 mm. The temperature averages 23 °C. Soils and land-use practices distribution were studied by Ssali and Isabirye (1998). The soils are *Petroplinthic hyperskeletic leptosols* at the summit, shoulder, and the upper, middle, and haplic luvisols on footslopes.

Instrumented, runoff plots measuring 15 m by 10 m were established on major agricultural land-use practices namely: banana, annuals, pastures / rangelands, and coffee. Each land-use practice was replicated three times except banana, which was replicated four times. Runoff was collected on storm basis. One-liter composite runoff sample, and a maximum of 100 g eroded sediment collected from the set of runoff plot divisors, were taken to the Laboratory for the determination of eroded sediment concentration and nutrient levels, respectively. Runoff was oven dried at 105°C, while the 100-g sample was air-dried. The latter were aggregated per season and analyzed for nutrient contents using methods described by Okalebo et al. (1993). Soil samples were analyzed for P using Foster's method (1972).

Water samples were collected regularly (bi-monthly) from the three hydrological stations: Kibaale, Bukoora and Kisoma. During cropping seasons very intensive sampling was done at the three stations. Water samples were collected every two days and parameters which were measured included: pH, conductivity, temperature, DO, suspended solids, BOD, Kjeldahl nitrogen, ortho-P, total P, dissolved Si, SO4, COD, and river discharge (World Bank, 1999). In this study only TSS (total suspended solid), TN (total nitrogen) and TP (Total available phosphorus) were considered.

A semi detailed land-use map (from National Biomass 1:120000) was used in this study. The average coverage of the different agricultural land use types, within the "cultivated land unit" was estimated by means of transects. A 100 m wide perpendicular transect was laid down at 100 m intervals along the main transect. On average a 1.5 km long transects were randomly established in each watershed. Eight watersheds were mapped in the two micro-catchments. A contour map (1:50000) was used to generate a Digital Elevation Model for the area. Rainfall amount and intensity were recorded from 20 raingauges scattered in the selected micro-catchments. The rainfall map was generated from rain gauges data, and erosivity classes were determined according to Moore's equation (1979) assuming it could be used for seasonal rainfall data. Since the level of organic matter is above 4% for all soils in the two micro-catchments, the soil erodibility was estimated from the expression derived from the global dataset (Torri et al., 1997). The total soil loss was estimated using the USLE model in a GIS environment and then calibrated with the actual soil loss from experimental plots. It was also assumed that intercropped garden could be separated in equal field of associated crops, bare land and land under fallow could be considered as soils cropped to annuals, and additional agricultural / artificial input was negligible.

The total load from agricultural land-use type at each of the three stations was then computed by summing outputs from all land-use:

$$\mathbf{L} = (\quad \mathbf{C}_{ij}\,\mathbf{A}_{ij}\,\mathbf{S}_{ij})$$

Where **L** is the total load (kg), $\mathbf{C}_{ij}$: concentration of a specific nutrient for a given season (kg/kg of soil), $\mathbf{A}_{ij}$: the area covered by a specific land-use practice (ha), $\mathbf{S}_{ij}$: soil loss from that specific land-use practice (kg/ha/ season).

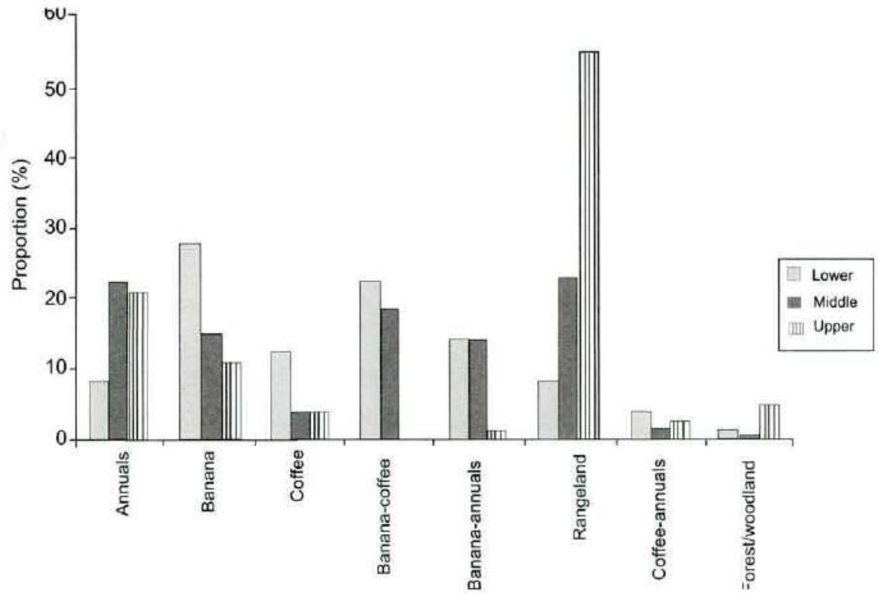
TS, TN, and TP were correlated to corresponding parameters recorded from the drainage network. Bukoora being the lowest sampling point near the Lake mouth, its nutrient load was considered as the sub-catchment export to the Lake.

Results and discussion

Major agricultural Land-use practices and their landscape distribution

The major land use types and their distribution along the landscape are presented in Figure 1. Six major agricultural land-use types were identified in the study area. They included banana, coffee, annual crops, banana-annual crops, banana-coffee, coffee-annual crops, and grazing land. Annual crops occurred mostly on the middle and upper portion of the landscape. Banana were dominant on the lower backslope. Banana-coffee and banana-annual crops were mainly located on the lower and middle backslope. Grazing land was a

Figure 1: Land-use types distribution along the landscape.



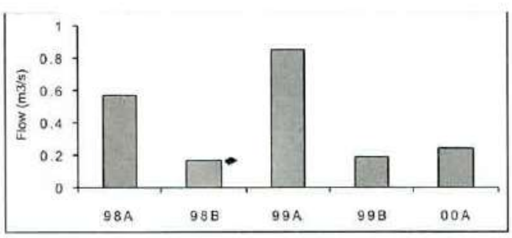
dominant practice on the upper backslope. Banana and grazing land proportions followed opposite trends. Aereal coverage proportion of Banana decreased as one moves upward on the landscape while grazing land area increased. The proportion of Forest / woodland within the cultivated land was very small (approximately 1%). This seems to illustrate the population pressure exerted on the land resources. The observed distribution of different agricultural land –use types colaborate well with earlier observation in the area (Ssali and Isabirye, 1998). This distribution of land-use type is dependent on the soil associations and geomorphology as both are closely linked to the topography/landscape. Banana and coffee are grown on rolling slope with relatively deep soils on the lower backslope, valley and flat topped ridges. While grazing of animals is mainly on steepslopes, poor and shallow soils found on the middle and the upper segments of the landscape. Grazing is also practised in the valleys where the soils are relatively shallow and clayey.

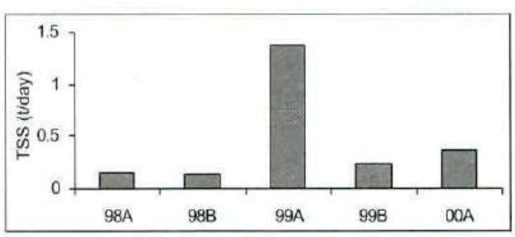
Forest / woodland within the cultivated land was very small (approximately 1%). This seems to illustrate the population pressure exerted on the land resources. The observed distribution of different agricultural land –use types colaborate well with earlier observation in the area (Ssali and Isabirye, 1998). This distribution of land-use type is dependent on the soil associations and geomorphology as both are closely linked to the topography/landscape. Banana and coffee are grown on rolling slope with relatively deep soils on the lower backslope, valley and flat topped ridges. While grazing of animals is mainly on steepslopes, poor and shallow soils found on the middle and the upper segments of the landscape. Grazing is also practised in the valleys where the soils are relatively shallow and clayey.

Temporal trends of loads in Lake Victoria tributaries

The temporal pattern of the flow, TSS, TP and TN loads from the two major tributaries of Lake Victoria in Rakai (Bukoora sub-catchment), is shown in Figures 2, and 3. The temporal load was site specific.

Figure 2: Average flow, TSS and TP and TN loading within the Kisoma river (1998 – July 2000)





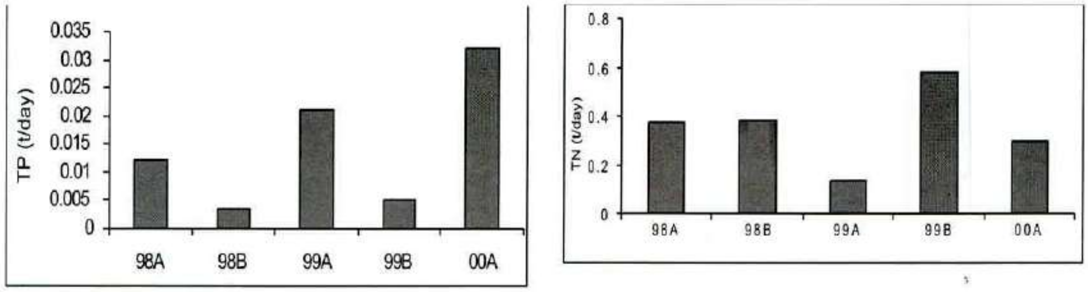
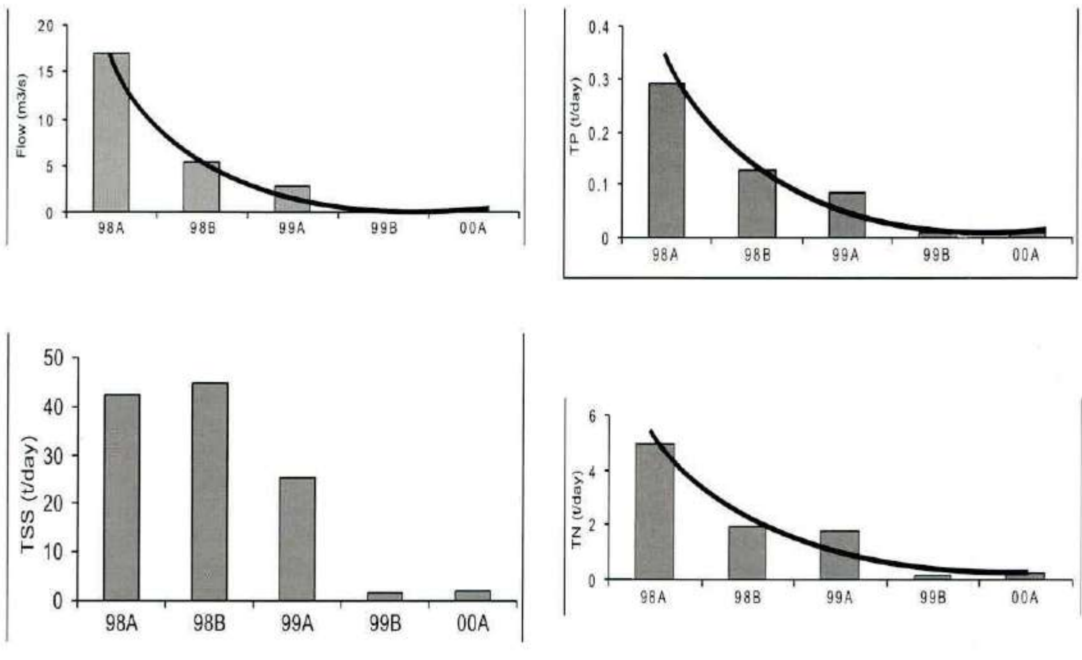


Figure 3: Average flow, TSS and TP and TN loading within Kibaale river (1998 – July 2000).



Load increase for both TSS and TP was highest during the long rains at Kisoma. The highest TSS loading was observed during the long rains of 1999 and for P it was during the long rains of 2000. The peak for TN was recorded during the short rains of 1999. TSS followed the flow pattern (R=0.79).

For Kibaale, a monotonous (exponential type) decrease of the flow with time was observed. The same pattern was observed for all parameters, except TSS for which, the load was quasi uniform during the two growing seasons of 1998. Then it declined also for the two other years.

A similar pattern of nutrient loads to that of Kibaale was observed for the flow as well as for other the different parameters (TSS, TN, and TP) ($p<0.05$), despite a steady increase in nutrient concentration from November 1999. According to the water quality rating (Champ, 1991) ; Kibaale (1.1 – 50.77 $mg/m^2/yr$) was excessively enriched stream during the long rains of 1998, while the P load from the two micro-catchments (1-54 $mg/m^2/yr$) was excessively enriched during the two growing seasons of 1998. The P range of (0.6 – 5.6) indicates that Kisoma was a cleaner stream during the three years. During the same period the concentration of N was rarely above the limit of 10 mg/l (3% of cases for Kisoma and 8 % of cases for Kibale and in the two

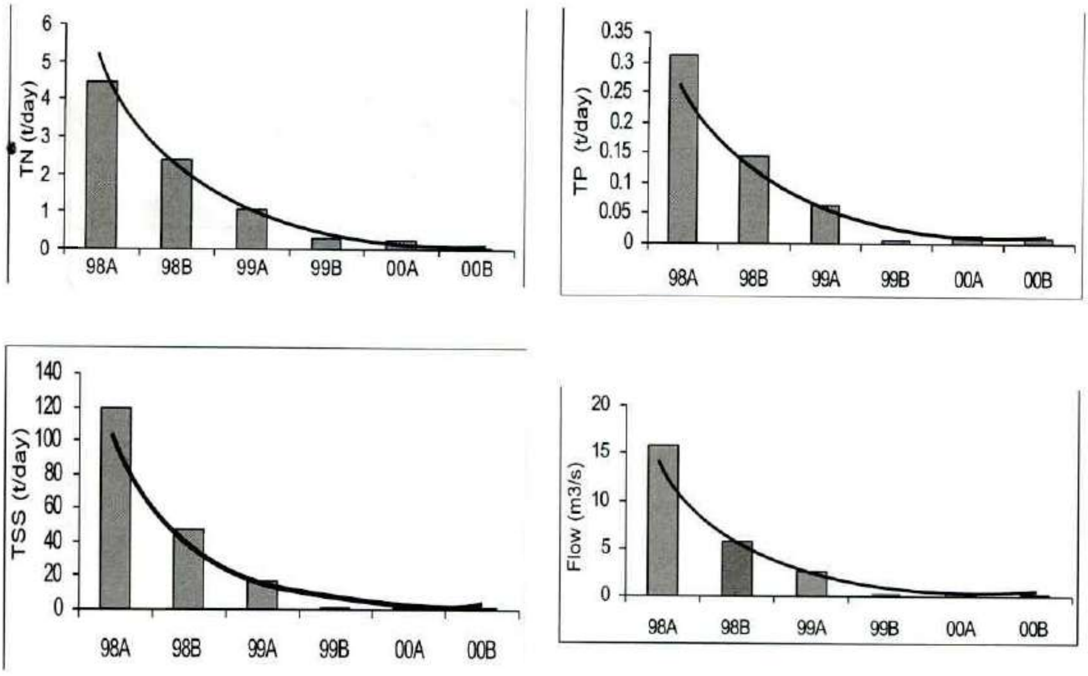


Figure 4: Flow, TSS and TP and TN loading within the two micro-catchments (1998 – 2000).

micro-catchments). Kibaale (0.26 – 7.77 t/km^2/yr) and Kisoma (0.02- 0.24 t/km^2/yr) were sligtly loaded with TSS, while the load from the two micro-catchments was moderate (20.7 t/km^2/yr) during long rains of 1999 and slight for the remaining period (Ridgway, 1995).

The total loads from the sub-catchment are shown in Figure 4. They present similar patterns to Kibaale except that TSS decreased overtime.

Sediment and nutrient exports from the two micro-catchments

Soil and nutrients exported from the major agricultural land-use practices of the two micro-catchments during the year 1999 are presented Table 1.

Soil loss varied during seasons ($p=0.009$); with the highest losses observed during the short rainy season. Only soil loss from coffee remained significantly the same for both seasons. Soil loss ranged between 4.86 t/ha (on banana) and 11.73 t/ha (on rangelands), and between 19.62 t/ha (on Coffee) and 31.48 t/ha (on rangelands). The concentrations of N and P were similarly high for all agricultural land-use practices and across both seasons ($p \leq 0.05$). The total export of soil and nutrients (N and P) followed the soil loss trends. Short rains export of TN per unit area was higher than the long rains one, but the export per unit area of TP increased significantly only in Coffee and rangelands. During the long rains TP exported per unit area ranged between 0.19 kg/ha (coffee) and 0.63 kg/ha (annuals) and between 0.52 kg/ha (banana) and 4.82 kg/ha (rangelands) for short rains. TN export per unit area at least doubled during the short rains ; and ranged between 19.4 kg/ha (banana) and 22.4 kg/ha (annuals) during that period.

The pattern and magnitude of nutrient concentration in eroded sediments was attributed to the difference in behavior of the different land-use practices, nature of parent materials on which they are established across the landscape. It also depends on the topography, hydrological properties of soils and their management, high aggressivity

of the rains, variation in seasonal total precipitation and rainfall intensities, and frequencies.

Micro-catchments soil and nutrient exports and loads correlation.

Correlation factors between soil exported from agricultural land and the level of pollutants loaded in the two tributaries and from the two micro-catchments is given in Table 2.

In all cases, the relationship is moderate to strong between the seasonal loads and exports ($p<0.05$). At Kibaale station a strong correlation, ranging from 0.70 to 0.73, was observed between the exports and the loads

Table 1: Soil and nutrient exports from the different agricultural land-use practices in the Bukoora sub-catchment.

Period of the year	Land-use	N %	P mg/kg	Soil loss kg/ha	TN * exported kg/ha	*TP exported kg/ha
Long rains 1999	Annuals	0.36	303.00	9079	8.1	0.63
	Banana	0.34	384.00	4855	4.1	0.43
	Coffee	0.39	99.00	8358	8.1	0.19
	Pasture	0.28	384.00	11730	8.2	1.03
Short rains 1999	Annuals	0.32	198.00	28173	22.4	1.28
	Banana	0.36	105.00	21629	19.4	0.52
	Coffee	0.38	413.00	19619	18.6	1.86
	Pasture	0.24	668.00	31480	18.8	4.82
Lsd ($p \leq 0.05$) accross seasons		Ns	Ns	11987	8.42	1.50

* TN and TP represent the average total nitrogen and total available phosphorus lost per ha of land in the two micro-catchments; respectively.

($p<0.05$). At Kisoma station the correlation was strong to very strong (0.70 and 0.93). Very strong correlation was also observed between TN exported and TN loaded. The correlation between exports and loads from the two micro-catchments was, in general, moderate (0.64 and 0.67). The correlation pattern was similar to that of Kibaale, with relatively low strength.

The data shows that agricultural land is an important contributor of sediments and nutrients (>41% for the sub-catchment, >50% for Kisoma and Kibaale), though not the only one! It also indicates that a number of processes occur between the Kibaale station and the two micro-catchments outlet that leads to the reduction of the load. This is attributed to the wetland filtration / purification / extraction process within the the tributaries.

Table 2: Correlation factor between exports and load parameters in Bukoora sub-catchment

Site	Land exports	Micro-catchments loads		
		TSS	TP	TN
	TSLE(105° C)	0.70	0.93	0.85
	TP		0.70	
Kibaale	TN			0.73
	TSLE(105° C)	0.70	0.72	0.93
	TP		0.81	
Kisoma	TN			0.90
2 micro-catchments	TSLE(105° C)	0.64	0.64	0.67
	TP		0.64	
	TN			0.65

Conclusion

This study demonstrates that lands are continuously degraded by water erosion in Bukoora and that a good portion of sediment and associated phosphorus is originating from agricultural lands. Long-term studies are needed to establish trends on the total exports of nutrients from different land-use practices of Bukoora and the associated loads. However, the pattern of correlation coefficients indicate that a lumped seasonal precipitation is not enough to model the export of sediment and associated loads in the two micro-catchments. There is need to develop a dynamic sediments and nutrient redistribution model, from uplands to low lands, within the sub-catchment for an efficient and sustainable management of resources.

Reference

Calamari, D.A., M.O. Aketch and P.B.O. Ochumba. 1994. Preliminary Hazard Assessment, Winam Gulf Basin Area; Conservation of Aquatic Environment, FAO, Rome.

Casey, H. smith, S.M. and Clarke, R.T. 1990. Trends and seasonality in the nitrate concentration and loads of the Bere stream (dorset) for the period 1966-1986. Chem. Ecol. 4: 85-94.

Chabeda P.I.M. 1983. A survey of eutrophication and water pollution loads in four rivers in the northern half of the Lake Basin Development Authority. Kisumu, Lake Basin Development Authority, Mimeo, 34p.

Champ, W.S.T. 1991. The impact of landspreading manures on fisheries resources. Proceedings of Environmental Impact Conference, Teagasc Research Centre, Johnstown Castle, Wesford.

Crul, R.C.M. 1995. Limnology and hydrology of Lake Victoria, studies and reports in hydrology 53. UNESCO publishing.

Dunne, T. 1974. Suspended sediment data for the rivers of Kenya, report to ministry of water developmemt, unpublished, 122 pp.

Foster, H. L. 1972. Rapid routine and plant analysis without automatic equipment I. Soil analysis. East African Agricultural and Forestry Journal. October 1972, pp 125-130.

Harris, G.L. and Parish, T. 1992. Influence of farm management on leaching of nitrate from former flodlands in a lowland clay catchment. In: P.A. Carling and G.E. Petts (Eds), Lowland Floodplain Rivers, Wiley, London, pp. 203-216.

Kaupi, L., Pietilainen, O.P, and Knuutila, S. 1993. Impacts of agricultural nutrient loading in Finnish watercourses. Water Sci. technol., 28:461-471.

Lehman, J.T., and D.K. Branstrator. 1993. Effects of nutrients and grazing on the phytoplankton of the Lake Victoria, Verh. International Verein. Limnol., Vol. 25