African Journal of Agricultural Research Vol. 8(1), pp. 77-85, 8 January, 2013
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.963
ISSN 1991-637X ©2013 Academic Journals

Full Length Research Paper

Soil and nutrient losses along the chronosequential forest recovery gradient in Mabira Forest Reserve, Uganda

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Accepted 27 September, 2012

Information on the effect of Mabira Forest Reserve degradation on water, soil and nutrient losses is scanty. This study was carried out to quantify runoff, soil and nutrient losses in six restoring forest regimes namely: 0 to 3, 10 to 20, 20 to 30, 30 to 40, 40 to 50, and >55 years of last disturbance. In each, a plot measuring 150 by 50 m was demarcated. Within this plot, three sub-plots each of 20 × 2 m and located 50 m apart were established for runoff, soil and nutrient losses measurement for period of two rain seasons. A runoff trap pre-calibrated to collect 1% of runoff was installed on each sub-plot. In addition, the forest regimes were characterized for some physio-chemical properties. Overall, annual runoff and soil loss across the forest regimes were low ranging between 20 to 160 m^3ha^{-1} and 10 to 380 kg ha^{-1}, respectively. Runoff and soil loss followed a parabolic trend along the forest age with the minimum in the 20 to 30 years forest regime. Annual nitrogen, phosphorus and potassium losses significantly varied from 0.11 to 4.26, 0.01 to 0.18 and 0.08 to 6.63 kg ha^{-1} respectively across the forest regimes. Bulk density was highest in the 30 to 40 year regime.

Key words: Soil erosion, bulk density, forest degradation.

INTRODUCTION

Whereas soil erosion and its control have been well documented worldwide, it still contributes significantly to soil functional degradation especially in Sub Saharan Africa (Smaling, 1993; Sanchez et al., 1997). In addition to affecting ecosystem services provided by the soil resource, erosion also reduces soil nutrient availability. Over the years, maintenance of vegetation cover - like forests, has been one of the common ways of controlling soil erosion (Coelho et al., 2001). However, in Uganda, rampant degradation of forests has persisted leading to grave environmental and ecological concerns (Banana and Sembajjwe, 2000). Regrettably, forest degradation has been attributed largely to anthropogenic activities other than climatic or natural causes. Notable of the human-induced causes of forest loss are conversion of forests to agriculture, overgrazing and firewood and timber cutting (World Wildlife Fund and McGinley, 2007). Limited access to alternative sources for the numerous forest products by both the surrounding and distant communities is a leading driver to over exploitation and disturbance vulnerability of forests.

Kayanja and Byarugaba (2001) reported that uncontrolled degradation and forest conversion to other land use types were seriously threatening Uganda's forests. Forest cover in Uganda has declined from 3,090,000 ha (12.7%) of the total country area at the beginning of the 20th Century, to 730,000 ha (3.6%) of Uganda's land area (Forest Department, 1999). In Mabira Forest Reserve (MFR), encroachment that took place mainly in the 1970's for settlement and agriculture resulted into 25% forest cover loss (BirdLife International, 2009). In MFR, the government intervened to reverse the

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trend of forest loss, and the encroachers were gradually evicted from the reserve in mid 1980s. This was achieved through either persuasion or forceful removal of all the encroachers. Because of the gradual removal of encroachment, the Reserve contains several blocks of different regeneration ages, which are the focus of this study.

Mabira Forest Reserve (MFR) is a tropical natural forest located between 32° 52' to 33° 07' E and 0° 24' to 0° 35' N, near the L. Victoria shoreline covering an area of 306 km^2 (Forest Department, 1999). Its altitude ranges between 1070 and 1340 m above sea level (asl) (Nature Uganda, 2001). Approximately 3.5 km^2 of the area comprises isolated hills lying above 1250 m asl. The slopes are generally undulating, and with numerous flat-topped hills and shallow valleys.

The soils are generally ferralitic with texture ranging from loamy to sandy clay loams (AES Nile Power, 2001), with isolated cases of waterlogged clays in the valley bottoms. The underlying rocks are composed of micaceous schists and shales of the Buganda-Toro system with ridges of quartzite and amphibolite. Its climate is tropical humid with bimodal rainfall from March to June and September to November for the long and short duration rains respectively with annual mean precipitation ranging between 1250 and 1400 mm. The annual mean minimum and maximum temperatures range between 16 to 17°C and 27 to 29°C, respectively (Lamto et al., 2010). The forest is a vital catchment for L. Kyoga because it is the origin of two rivers namely Musambya and Sezibwa (Environmental Alert, 2007) that drain into the lake.

The forest is rich in biota harbouring 47% of Uganda's total plant species (Baranga, 2007) many of which are on the list of globally endangered species (FAO, 1986). Its rich fauna includes 151 species of forest birds, 2 species of diurnal forest primates, 39 species of forest swallowtail and 218 species of butterflies including C*haraxes* (Baranga, 2007). Within MFR, there are 27 villages (Baranga, 2007) commonly known as enclaves, where subsistence farming is the primary activity for the 3,506 families within (BirdLife International, 2009). The most commonly grown crops are maize, cassava, bananas, sugarcane and beans. Additionally, a large section of the community is involved in some illegal activities like charcoal burning, pitsawing and collection of poles for construction as well as collecting medicinal and other plants to obtain further income.

Whereas several studies have been conducted in MFR and elsewhere in Uganda (Earth Trends, 2003; Pomeroy and Tushabe, 2004; Poulsen et al., 2005; Winterbottom and Eilu, 2006), these previous studies have focused largely on biodiversity, and there is limited information on the dynamics of soil physical and chemical properties, and nutrient losses in regenerating forests in Uganda. Therefore, the current existence of forest regimes at different recovery stages offers the opportunity for this study to assess the effect of forest regeneration age on runoff, soil and nutrient losses from Mabira Forest Reserve.

MATERIALS AND METHODS

Runoff, soil and nutrient losses measurements

Studies were conducted during the short season (September to December 2007) and long season (March to June 2008). Six sets of forest regimes representing 0 to 3, 10 to 20, 20 to 30, 30 to 40, 40 to 50, and over 55 years since the last disturbance were identified for this study. Because of difficult of getting several forest regimes with similar ages, replication was done within a forest regime. Within each forest regime, three runoff plots each measuring 2 × 20 m were installed 50 m apart to measure runoff using a pipe sampler (Ngigi et al., 2005). The erosion trap area was sealed off using several pieces of iron sheets measuring 3.3 m long and 0.25 m width. The plots were geo-referenced and a study area map drawn (Figure 1) in ArcView a GIS environment.

A clean container was tightly tied at the end of the collection pipe located at the posterior end of the erosion trap to collect the runoff via a small slit calibrated to take 1% the total runoff (Ngigi et al., 2005). However, each trap was calibrated using a known volume of water and determining the transmission coefficient. Total runoff (water and sediments) that collected in the container were quantified using a measuring cylinder every morning of the day following a rainfall event. The runoff samples were then put into clean plastic bottles and periodically delivered to the Department of Soil Science, Makerere University analytical laboratory for subsequent analyses. Event runoff was multiplied by the divider transmission coefficient to obtain the plot runoff, and then extrapolated to hectare basis, by multiplying the obtained number by 250. Runoff loss in a season was obtained by summing up runoffs registered for the different storms in that season. The two season runoff collections were eventually summed up to obtain the annual runoff per hectare.

In the laboratory, each runoff sample was thoroughly homogenized and immediately split into two known volumes. The first portion was filtered using a Whatman No. 1 filter paper and its contents oven-dried at 105°C for 24 h to determine the dry weight of the soil. The amount of soil loss in the plot was obtained by multiplying the sediment concentration by runoff (MacDonald et al., 2003) and transmission coefficient and then expressed on ha basis. The seasonal soil loss was computed by summing up the soil losses from all the season collections. Finally, annual soil loss was determined by combining the losses of the two seasons. The second portion of a known volume was also filtered as the first portion, air dried and used for macro nutrient loss determination. Three macronutrients namely: nitrogen, phosphorous and potassium were measured for assessment of nutrient loss. All the three nutrients were determined following standard procedures described by Okalebo et al. (2002). Seasonal nutrient losses were estimated by multiplying by seasonal soil loss and computed on a hectare basis. Finally, annual nutrient losses were computed by summing seasonal losses.

General physical and chemical site characterization

Soil samples were taken around the runoff plots in order to characterize the study area in terms of its physiochemical properties. Bulk density was determined using the core oven drying method (Blake and Hartage, 1986). Four cores each measuring 5 cm long by 5 cm internal diameter were used to take samples from

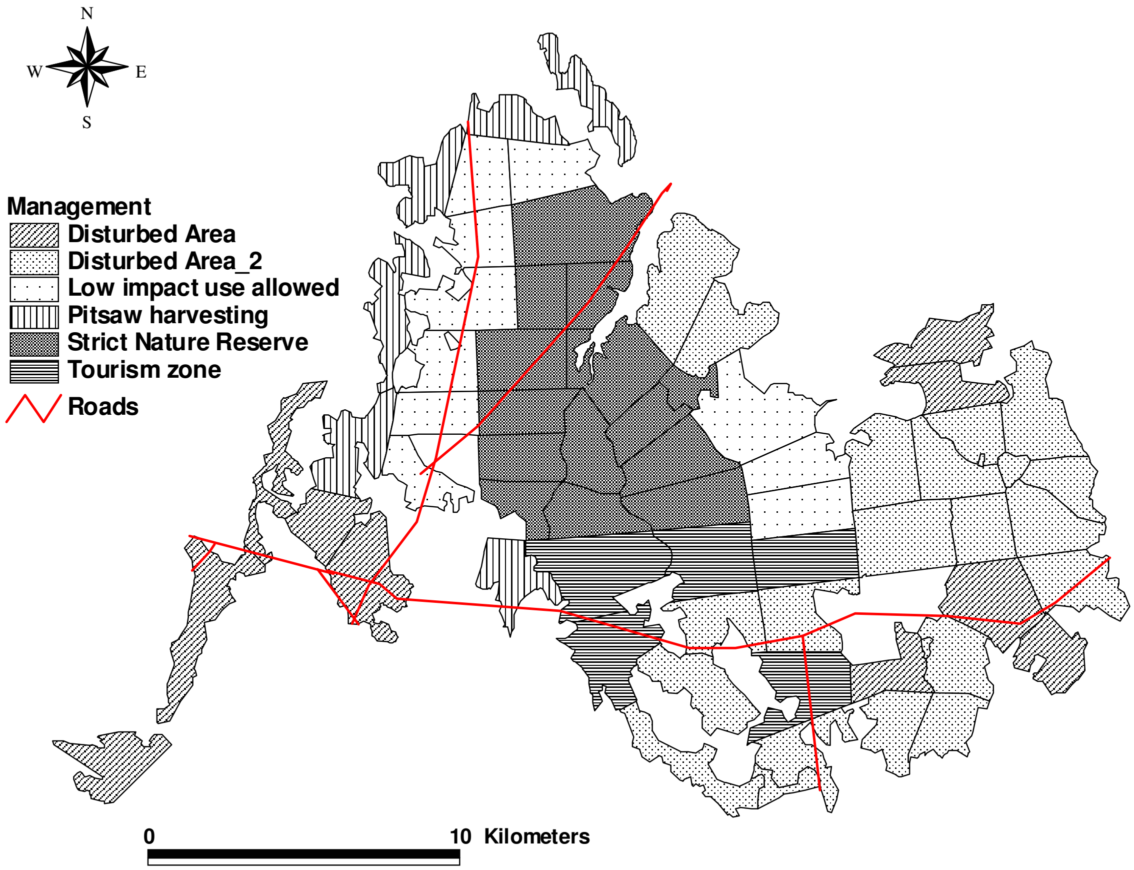

Figure 1. Mabira Forest Reserve showing different forest land uses and study area.

two soil depths of 0 to 15 cm and 15 to 30 cm for top and sub soils respectively. The core samples were taken about 3 m away from the mid-length of each sub-plot. Composite soil samples were taken around the plot using a soil auger. A total of four samples were collected at each sub-plot, two from 0 to 15 cm and the rest from 15 to 30 cm. These samples were used to probe some of the physiochemical base of the area. The soils were analyzed for pH, organic matter (OM), total nitrogen (N), available phosphorus (P), exchangeable bases (sodium, calcium, magnesium and potassium), micro nutrients (iron, zinc, manganese and copper) and texture (Okalebo et al., 2002).

Rainfall determination

Rainfall was measured for two seasons using an electronic rain gauge with DT1 - One Rain Channel Data Logger manufactured by Environmental Manufacturers (EM) Ltd of United Kingdom (www.waterrauk.com/pages/product/Raingauge_Loggers.asp). The gauge was installed in the forest regime of 20 to 30 years located near the Eco-Tourism Centre at Najjembe. Data was downloaded every fortnight throughout the study period. Adjacent to this rain gauge, a locally fabricated manual rain gauge was installed. Similar manual gauges were installed in all the other forest regimes. The fabricated manual gauges were calibrated against the electronic one. Water that collected in the manual gauge was measured immediately after a rain event. Seasonal rainfall was determined by summing up all the season rain events. The two seasons' rainfall was then summed up to obtain annual rainfall per forest regime.

Data analysis

Data were entered in MS Excel (ref) and then imported into Genstat (VSN International, 2000) for statistical analysis. Mean soil, runoff, and nutrient losses from the different treatments were separated by a one-way analysis of variance (ANOVA) in Genstat.

RESULTS AND DISCUSSION

Rainfall characteristics of the various forest restoring regimes

There were two sets of forest regimes without intra-rainfall variation but with significant inter-variation. The first set of all forest stand ages of at least 20 years had significantly higher amount of annual rainfall than the other set of young forests (Figure 2) averaging 2000 and 1000 mm respectively. The higher amount of rainfall in the relatively older forests compared to young ones was also reported by Turner et al. (2009). This is an indication of the crucial role of mature forests in hydrological control. It also signifies the hydrological disruption as a result of forest ecosystem interference (Wang et al., 2009).

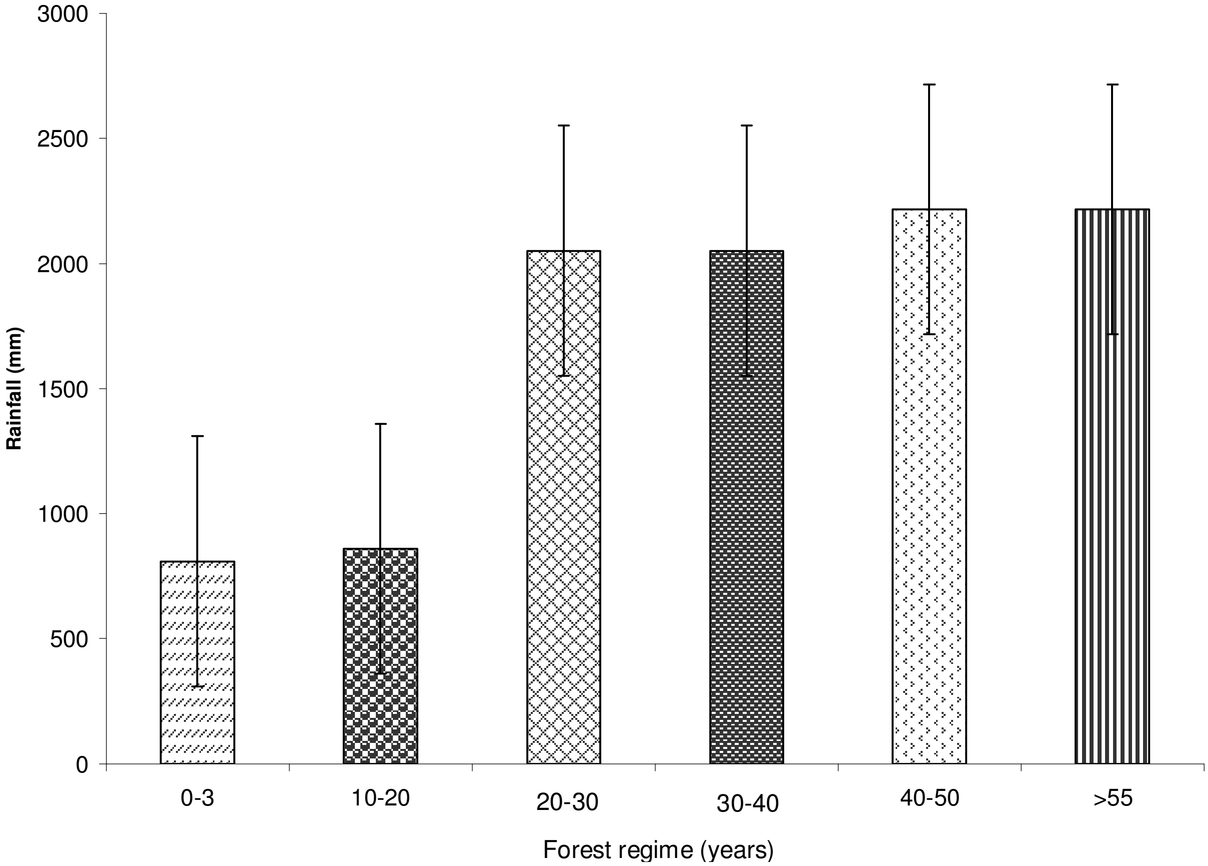

Figure 2. Annual rainfall in Mabira forest restoring regimes.

General physio-chemical characteristics of the study area

The soils in Mabira Forest Reserve were all rich in most of the nutrients required for normal or optimum plant growth (Table 1) though with a lot of variation among the forest regimes. For instance, soil pH ranged between 5.66 and 7.02 with highest observed in forest regime of 20 to 30 years while least in that of 40 to 50 years. Organic matter also differed with age of forest where it was significantly higher in those of over 40 years than in the younger ones. Phosphorus did not vary so much among the forest regimes except for the block of 20 to 30 years that had more but overall, the amount was below optimum values across all the forests. Potassium, magnesium and calcium were very high for all soils and differing significantly ($p < 0.05$) among the forest ages with the 20 to 30 year forest stand age having the highest values except for magnesium that generally decreased with forest age. Soils in all the regimes were mainly clay loam (CL) except for the regimes of at least 45 years ago. Though there were significant variations in the physio-chemical properties, there was no clear trend attributable to forest stand age apart from organic matter that increased with forest stand age. This differed from the findings of Sharma et al. (1985) under *Alnus nepalensis* plantation where most of the physiochemical properties improved with forest age. Therefore, the observable differences except organic matter could not be explained by age differences alone but could be possibly due to the intrinsic soil characteristics.

The bulk densities of Mabira soils were very low, but varied significantly with soil depth and forest regime (Table 2). Consistently, sub soils had higher bulk densities over the top soils. Similarly, porosity varied with soil depth and forest regime but unlike the bulk density, the top soils were more porous than the sub soils thus in agreement with the findings of Dudley et al. (2002). The low bulky density and high porosity in the top soil is generally due to modification by the rich organic matter in the upper layers owing to the littering effect of the trees. This is in agreement with earlier findings of Haque and Karmakar (2009). The high porosity in the 0 to 3 year forest stand is attributed to macro pores created as a result of decaying effect of the roots of the trees formally in the forest before it was degraded as was also reported by Noguchi et al. (1997). The high bulk density and low porosity in the sub soils is characteristic of a relatively more developed soil structure of the mineral soil than the organic soil on the top (Murty et al., 2002). The generally

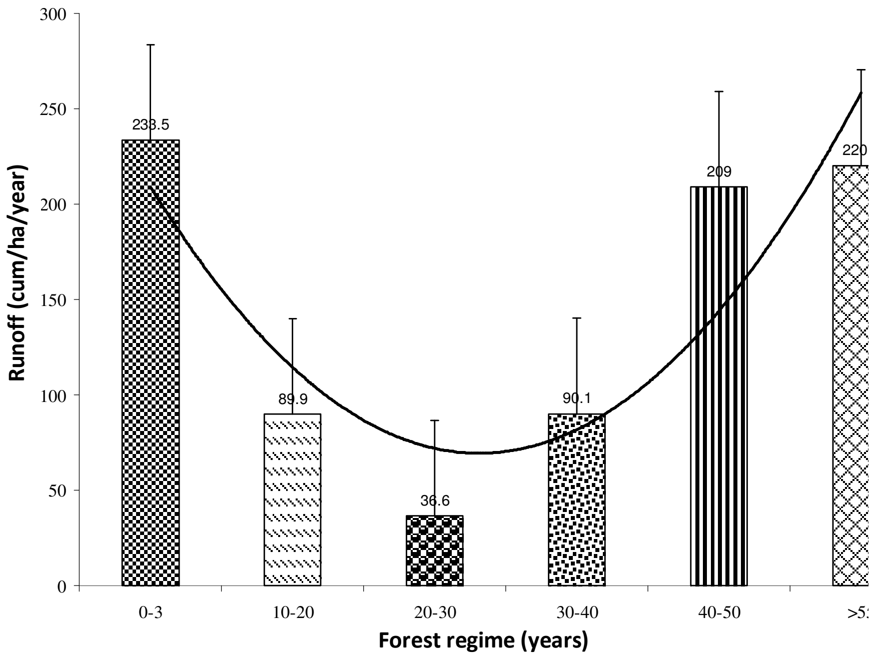

Figure 3. Annual runoff in Mabira chronosequential forest stands.

low bulk density and high porosity in Mabira Forest soils could also be attributed to the influence of the litter and roots in modifying soil structure and soil pores (Dudley et al., 2002).

Runoff from the various Mabira forest regimes

The annual runoff ranged between 36.6 and 233.5 $m^3ha^{-1}year^{-1}$ averaging 93 m^3/ha per annum (Figure 3). Two pair-wise sets of forest regimes without intra-variations but with significant inter-variations were observed. The first set with the highest amount of runoff was observed in three forest stand ages of 0 **to** 3, 40 **to** 50 and over 55 years and the low amount in forest stand ages of 10 **to** 20, 20 **to** 30 and 30 **to** 40 years with runoff exhibiting a parabolic trend across forest stand ages. The average runoff for the two forest stand age categories was 214 and 72.2 $m^3ha^{-1}year^{-1}$**,** respectively. The high runoff in the youngest forest of 0 **to** 3 year**s** was similarly reported by Tiwari (2009) for agricultural land. This can be attributed to limited vegetation cover that would have otherwise acted as runoff breakers through prevention of detachment and modification of infiltration (Young, 1989, Gyssels et al., 2005). However, the unusually high runoff in the old forest stands is difficult to explain but as Coelho et al. (2001) asserted, it could be due to the persistent water saturation most of the time that reduced the soil infiltration capacity thus favoring runoff. This was so despite the mature forests having sandy clay loams as opposed to the clay loams in the young forests. The latter are expected to be slightly more liable to logging than the former.

Generally, runoff was very low in all the forest stands compared to that reported under agricultural land in the Lake Victoria Basin (Majaliwa, 1998; Johnny, 2004; Mulebeke, 2004; Majaliwa et al., 2003) and elsewhere (Floor, 2000; Gafur et al., 2003). However, similar runoff results were reported earlier by Aina (1993) under natural erosion from forested lands. The general low level of runoff implies that even under degraded conditions, the vegetation cover under forest can minimize runoff compared to the less vegetated areas.

The percentage rainfall that ended up as runoff ranged between 2 and 20% (Figure 4). The percentage rainfall amount converted into runoff also followed a parabolic trend with forest age. Whereas the youngest forest of 0 to 3 years had the least amount of rainfall, it exceedingly had a higher percentage of rainfall that resulted into runoff over all the other forests. The least run off to rainfall ratio was observed for the 20 to 30 years forest. The relatively low vegetation cover (canopy and ground cover) in the 0 to 3 years forest could have encouraged runoff over infiltration unlike in other forest stands (Coelho et al., 2001). The moderately high rate of rainfall resulting into runoff in the other forest stand was subjective to the consistently high moisture content in those forests almost throughout the year.

Soil loss from the various Mabira forest regimes

The annual soil loss across the forest ages ranged from10 to 513 kg ha^{-1} $year^{-1}$. Like runoff, the forest of 0 to

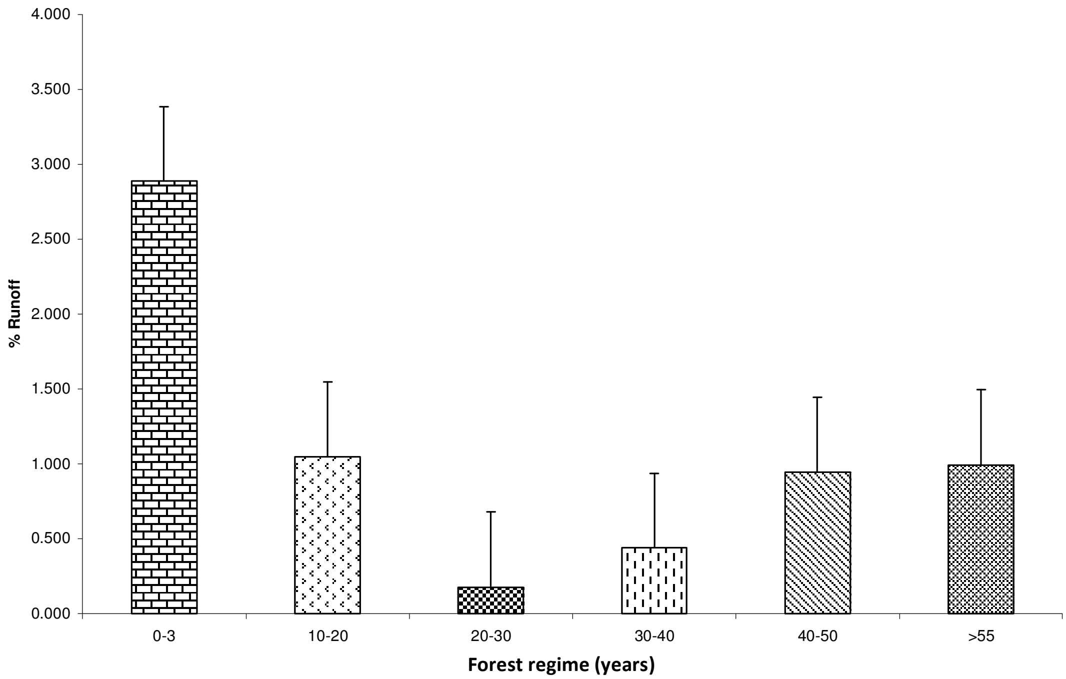

Figure 4. Percentage runoff to rainfall.

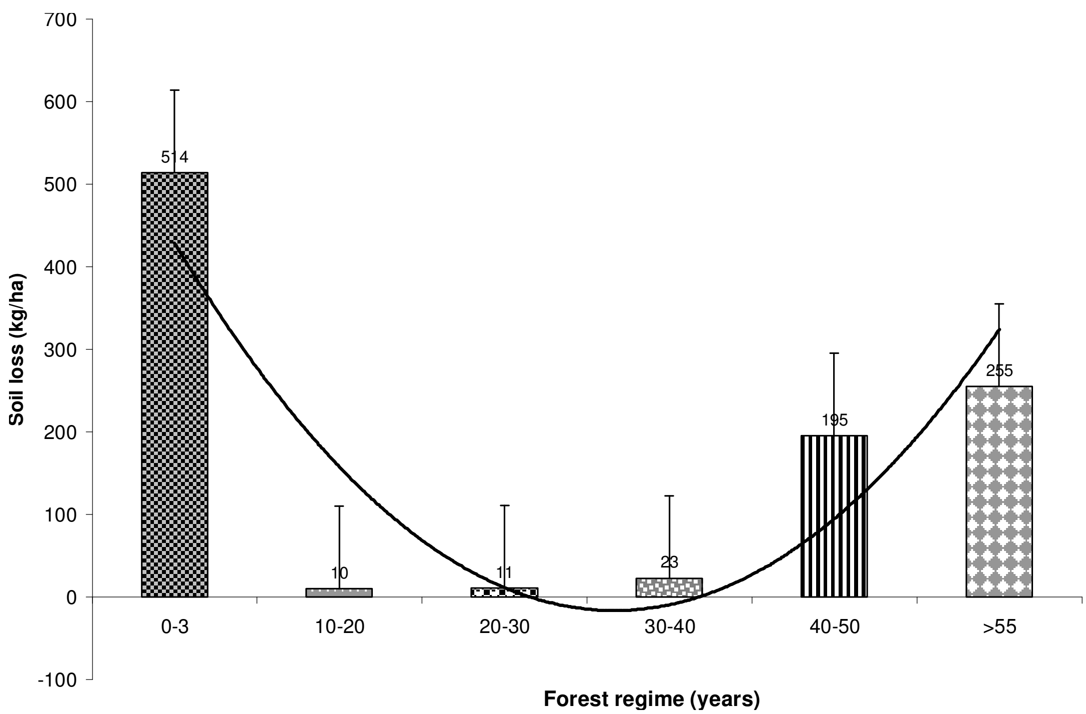

Figure 5. Annual soil loss from Mabira chronosequential forest stands.

3 years experienced the highest soil loss. However, if this young forest (0 to 3 years) is excluded, soil loss increased exponentially with forest age but if retained, a parabolic trend is exhibited with the least soil loss between 10 and 40 years forests (Figure 5). As was also reported by de Vente et al. (2005) and Gyssels et al. 2005), soil in the youngest forest of 0 to 3 years was more exposed to raindrop impact, detachment and thus

Table 1. Chemical and textural properties of MFR regenerating regimes.

Parameter	Units	Forest stand age					
		0-3	10-20	20-30	30-40	40-50	>55
Av. P	mg/kg	$9.20^{a,b}$	5.80^{b}	12.90^{a}	7.20^{b}	7.30^{b}	6.80^{b}
OM	%	4.08^{e}	3.53^{e}	4.79^{e}	3.26^{e}	7.12^{d}	7.02^{d}
pH		5.72^{h}	6.22^{g}	7.03^{f}	6.21^{g}	5.66^{h}	5.79^{h}
K		0.57^{j}	0.30^{k}	0.88^{i}	0.34^{k}	0.69^{j}	$0.76^{i,j}$
Mg	cmol/kg	4.71^{l}	4.27^{lm}	3.92^{n}	3.60^{n}	1.61^{o}	2.23^{o}
Ca		8.37^{q}	11.46^{q}	24.93^{p}	9.49^{q}	5.23^{r}	4.79^{r}
Na		0.50^{t}	0.57^{s}	0.51^{t}	0.44^{t}	0.52^{t}	0.51^{t}
Fe		59.7^{u}	24.3^{w}	18.7^{w}	39.80^{v}	62.5^{u}	56.5^{u}
Cu	mg/kg	2.77^{z}	6.46^{x}	7.38^{x}	3.38^{y}	1.88^{z}	3.52^{y}
Mn		138.8^{1}	141.2^{1}	146.2^{1}	142.6^{1}	118.6^{2}	149.5^{1}
Zn		4.03^{ii}	8.24^{i}	7.88^{i}	3.67^{ii}	2.00^{iii}	4.80^{ii}
Sand	%	46	37	38	48	58	57
Clay		26	41	43	25	27	24
Class		CL	CL	CL	CL	S CL	S CL

Figures with similar letters appended along the rows are insignificantly different whereas those with differing letters are significantly differing.

Table 2. Bulk density and porosity for top and sub soils of Mabira chronosequential forest stands.

Forest stand age (year)	Bulk density (g/cm^3)		Porosity (%)	
	Top soil	Sub soil	Top soil	Sub soil
0-3	0.74	0.79	72.3	70.7
10-20	0.82	0.93	69.6	65.5
20-30	0.82	0.84	69.6	68.8
30-40	0.95	1.05	64.9	61.1
40-50	0.81	0.87	70.2	68.3
>55	0.8	0.93	70.4	65.5

$LSD_{0.05}$ (Forest stand age) = 0.07; $LSD_{0.05}$ (soil depth) = 0.11

(displacement along with runoff as a result of limited vegetation cover and litter. The low soil loss in older forests could be due to improved vegetation cover as well as the binding action by plant roots (Gyssels and Poesen, 2003) and improvement of soil physical properties (Gyssels et al., 2005). The relatively high soil loss in the intact forest with good vegetation cover invalidated the findings of Stolte (1997) but tallied with those much earlier reported by Patric (1976).

The conditions that favored runoff could have contributed to the trend of soil loss in the forest regimes. Low water infiltration as a result of the soil being kept almost saturated with moisture in the old forest could have favoured both runoff and soil loss. Generally, soil loss was too small measuring about 1/400th and 1/1000th of annual values reported by Majaliwa (1998) and Majaliwa et al. (2003).

Nitrogen, phosphorus and potassium losses

Table 3 shows the annual nutrient losses from the various forest regimes in Mabira Forest Reserve. Noteworthy, is the highest annual nitrogen and phosphorus losses experienced in the 0 to 3 years forest stand. The loss for the two nutrients drastically reduced in the next 10 to 20 years forest stand before gradually increasing with forest stand age. Potassium loss did not follow any particular trend though like N and P it was significantly more lost in 0 to 3 years forest stand. The

Table 3. Annual nutrient losses in Mabira chronosequential forest stands.

Forest stand ages (year)	Nutrients lost (kg ha^{-1})		
	N	P	K
0-3	5.36	0.30	39.81
10-20	0.11	0.01	0.99
20-30	0.16	0.01	7.49
30-40	0.23	0.02	0.33
40-50	3.06	0.25	5.94
> 55	4.38	0.20	9.93

average annual N, P and K losses for the study area were 4.38, 0.200 and 9.93 kg ha^{-1} year^{-1} respectively.

The losses are generally very small in all the forest stand ages but in harmony and contrast with those obtained by Bormann et al. (1983) and Miller and Newton (1983) respectively. Most likely the same factors described earlier for influencing runoff and soil loss across the forest ages could have positively contributed to the nutrient losses.

CONCLUSIONS AND RECOMMENDATIONS

Excluding 0 to 3 years forest stand, runoff in Mabira forest was very low compared to the figures reported on agricultural land but increased with increasing years of last forest disturbance. The forest stand age of 0 to 3 years recorded the highest soil loss. However, after ten years of regeneration, there was a gradual increase in soil loss with increase in forest age. Results indicate that even under disturbance, the forest ecosystem was still capable of providing the function of runoff, soil and nutrient loss reduction. The average annual soil loss as well as nutrient losses in Mabira Forest was very low compared to losses reported in agricultural land. Of the three macro nutrients, potassium was more lost followed by nitrogen in runoff. Fortunately, the nutrient losses are too small to affect forest regeneration. The bulk density and porosity are in permissible ranges for soil and water conservation under a forest ecosystem.

Since the forest ecosystem is still superior in controlling soil, water and nutrient losses, it is recommended that forests should be conserved. It is also recommended that broader studies to cover watershed nutrient and soil losses be undertaken since this study only considered point losses.

ACKNOWLEDGEMENTS

The authors acknowledge the European Union for the funding under the FOREAIM Project (INCO-CT-2005-510790); The National Forest Authority Staff in Mabira
funding under the FOREAIM Project (INCO-CT-2005-510790); The National Forest Authority Staff in Mabira
Forest Reserve; and the field assistants in Mabira for collecting runoff data.

REFERENCES

AES Nile Power (2001). Description of soils within the region, Appendix B1. Bujagali Project Transmission System, EIS.

Aina AO (1993). Rainfall runoff management techniques for erosion control and soil moisture conservation. Runoff control by basin tillage techniques. In: Soil tillage in Africa: Needs and challenges; FAO Soils Bull. 3:69.

Banana AY, Sembajjwe WG (2000). The Importance of Security of Tenure and Rule Enforcement in Urban Forests. In: Gibson C., M. A. McKean and E. Ostron (Eds). Forest Resources and Institutions, Chapter 4. FAO Corporate Document Repository.

Baranga D (2007). Observations on resource use in Mabira Forest Reserve. Afr. J. Ecol. 45(1):2-6.

BirdLife International (2009). Important Bird Area factsheet: Mabira Forest Reserve, Uganda. Downloaded from Data Zone at http://www.birdlife.org on 9/9/2010.

Blake GR, Hartage KH (1986). Bulk density. In: Klute, A. ed. Methods of soil analysis. Part 1. Physical and mineralogical methods—Agron. Monogr. 2:9.

Bormann FH, Likens GE, Fisher DW, Pierce RS (1983). Nutrient Loss accelerated by clear-cutting of Forest Ecosystem. Science 159:(3817):882-884.

Coelho AT, Galvao TCB, Pereira AR (2001). The effects of vegetative cover in the erosion prevention of a road slope. Environ. Manage. Health, MCB UP Ltd. 12(1):78-87.

de Vente J, Poesen J, Verstraeten G (2005). The application of semi-quantitative methods am reservior sedimentation rates for prediction of basin sediment yield in Spain. Esevier B.V. J. Hydrol. 305:63-86.

Dudley MD, Tate KW, McDouglad NK, Melvin RG (2002). Factors influencing soil surface bulk density on oak savannah Rangeland in Southern Sierra Nevada Foothills. USDA Forest Service Gen. Tech. Rep. PSW-GTR 184:131-138.

Earth Trends (2003). Biodiversity and Conserved Areas in Uganda. http://earthtrends.wri.org/pdf_library/country_profiles/bio_cou_800.pdf

Environmental Alert, (2007). Facts about Mabira. www.envalert.org/docs/BriefOnMabira.pdf

FAO, Food and Agricultural Organization, (1986). Early Agrometeorological crop yield forecasting. FAO Plant Production and Protection, by M. Frère and G.F. Popov. FAO, Rome, Italy. p. 73

Floor JA (2000). Soil: Erosion and Conservation. Accessed indicate date from: www.seafriends.org.nz/enviro/soil/erosion.htm

Forest Department (FD) (1999). The status of the biomass in Uganda. Biomass study report, Ministry of Environment, Water, Lands and Natural Resources, 1999.

Gafur A, Jensen JR, Borggaard OK, Petersen L (2003). Runoff and losses of soil and nutrients from small watersheds under shifting cultivation (Jhum) in the Chittagong Hill Tracts of Bangladesh. J. Hydrol. 279(1-4):293-309.

Gyssels G, Poesen J (2003). Importance of plant root characteristics in controlling concentrated flow erosion rates. Earth Surface Processes and Land forms 28(4):371-384.

Gyssels G, Poesen J, Bochet E, Li Y (2005). Impact of plant roots on resistance of soil to erosion by water: A review. Progress Phys. Geogr. 29(2):189-217.

Ngigi SN, Savenije HHG, Thome JN, Rockström J, Penning de Vries FWT(2005). Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. Agricultural Water Management 73:21-41. Elsevier.

Haque SMS, Karmakar NC (2009). Organic matter accumulation in hill forests of Chittagong region, Bangladesh. J. For. Res. 20(3):249-253

Johnny GM (2004). Soil erosion following forest operations in the Southern Piedmont of central Alabama. J. Soil Water Conserv. 59(4):180-185.

Kayanja FIB, Byarugaba D (2001). Disappearing forests of Uganda: The way forward. Curr. Sci. 81(8):936-947.

Lamto G, Okwakol MJN, Isabirye BE, Isabirye M, Kalema J (2010). Characterization of Mabira Forest CSM-BGBD benchmark area, Uganda. In: Rwakaikara-Silver, M.C; B.E. Isabirye; A.M. Akol; C. Nkwiine; M.J.N. Okwakol, J. Huising; P. Okoth; W. Brooijimans and T.B. Etyang (eds). Ecology and Management of Soil Biodiversity in Mabira Forest, Uganda. An Inventory. Towards Conservation and Sustainable Management of Below-Ground Biodiversity in Uganda, pp. 3-18.

MacDonald MA, Lawrence A, Shrestha PK (2003). Soil erosion. In: Schroth G. and F. L. Sinclair (Eds): Trees, Crops and Soil Fertility: CABI Publishing, CABI International, Willingford, Oxon, OX10 8DE, UK. Concepts Res. Methods pp. 325-343.

Majaliwa JGM (1998). Effect of vegetation cover development on soil loss from maize based cropping systems. MSc. Thesis, Makerere University.

Majaliwa JGM, Magunda MK, Tenywa MM, Semalulu O (2003). Soil erosion and pollution loading from agricultural land in Bukoora sub-catchment. Uganda J. Agric. Sci. 9:305-312.

Miller JH, Newton M (1983). Nutrient loss from disturbed forest watersheds in Oregon's Coast Range. Agro-Ecosyst. 8:153-167.

Mulebeke R (2004). Validation of a GIS-Use Model in a banana-based microcatchment of the L. Victoria basin. MSc thesis, Makerere University, Uganda.

Murty D, Kirschhaum MUF, Mcmurtrie RE, Mcgilyray H (2002). Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Global Change Biol. 8(2):105-123.

Nature Uganda (2001). Mabira Forest Reserve. International Bird Areas.

Noguchi S, Tsuboyama Y, Sidle RC, Hosoda I (1997). Spatially distributed morphological characteristics of macropores in forest soils of Hitachi Ohta Experimental Watershed, Japan. Springer Japan. J. For. Res. 2(4):207-215.

Okalebo JR, Gathua KW, Woomer P (2002). Laboratory Methods of Soil and Plant Analysis. A working manual. Tropical Soil Biology and Fertility Programme. Marvel EPZ, Kenya Press Ltd, Nairobi, Kenya. pp. 22-80.

Patric JH (1976). Soil erosion in Eastern Forest, Society of American Foresters. J. For. 74(10):671-677.

Pomeroy D, Tushabe H (2004). The State of Uganda's Biodiversity 2004. Makerere University Institute of Environment and Natural Resources/National Biodiversity Data Bank.

Poulsen AD, Hasashim ND, Eilu G, Liengola IB, Ewango CEN, Hart TB (2005). Composition and species richness of forest plants along the Albertine Rift, Africa. in I. Friis and Balslev (eds.). Plant diversity and complexity patterns. Local, regional and global dimensions. Biogiske Skrifter 55:129-143,

Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ, Izac AN, Mokwunye AU, Kwesiga FR, Ndiritu CG, Woomer PL (1997). Soil fertility replenishment in Africa: an investment in natural resource capital. In: Replenishing Soil Fertility in Africa, Soil Science Society of America Special Publication, Soil Science Society of America, Madison, WI. p. 51.

Sharma E, Amasht RS, Singh MP (1985). Chemical soil properties under five age series of *Alnus nepalensis* in Eastern Himalayas. Plant Soil 82:105-113.

Smaling E (1993). An Agro-Ecological Framework for Integrated Nutrient Management with Special Reference to Kenya. Landbouwuniversiteit te Wageningen, Waginingen, Netherlands. p. 19.

Stolte KW (1997). Soil Health. In 1996 National Technical Report on Forest Health, USDA, Forest Service. Washington DC.

Tiwari KR (2009). Runoff and soil loss responses to rainfall, land use, terracing and management practices in the Middle Mountains of Nepal, Acta Agriculturae Scandinavica, Section B - Plant Soil Sci. 59(3):197-207.

Turner TR, Duke S, Fransen B, Reiter M, Kroll AJ, Ward J, Bach J, Justice T, Bilby B (2009). Landslide density and its association with rainfall, forest stand age, and topography, december 2007 storm, Willapa Hills, Southwest Washington. Geological Society of America Abstracts with Program 41(7):335.

VSN International (2000). Software for biosciences. VSN International Ltd, 5 The Waterhouse, Waterhouse Street, Hemel Hempstead, HP1 1ES, UK.

Wang B, Yang Q, Liu Z (2009). Effect of conversion of farmland to forest or grassland on soil erosion intensity changes in Yanhe River Basin, Loess Plateau of China. Front. For. China. 4(1):68-74.

Winterbottom R, Eilu G (2006). Uganda Biodiversity and Tropical Forest Assessment. Report for United States Agency for International Development under the International Resources Group.

World Wildlife Fund and McGinley (2007). Central China loess plateau mixed forests. In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment).

Young A (1989). Soil fertility and soil degradation. In: Agroforestry for Soil Conservation. CAB International, Wallingford, Oxon, Ox 10 8DE.