THE EFFECT OF LAND USE PRACTICES ON POLLUTION DYNAMICS IN THE HIGHLANDS OF UGANDA

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Abstract

Smallholder agriculture in sub-Saharan Africa is characterized by poor farming practices, soil erosion, sediment deposition in low land areas and the subsequent water pollution. This study was designed to link agricultural management practices to nutrient and water use efficiencies of lowland wetland rice production systems, soil and water quality. Four major issues studied in this project include (a) quantifying the magnitude of upstream erosion (b) determining sediment loading rates in the streams (c) estimating sediment deposition in wetlands, with a view of understanding retention capacities and (d) assessing fertilizer use efficiency under rice cropping. The study was carried out in Manafwa catchment (314 km^2) within Mount Elgon which is a trans-boundary ecosystem located in Eastern Uganda and Western Kenya. A combination of field data collection, the application of stable isotopic techniques and modelling with soil water assessment tool (SWAT) in a geographic information system (GIS) platform and a cost-benefit analysis were used for assessing rice wetlands for socio-economic and environmental benefits. The soils in the upland were predominantly Lixic ferralsols (33.3%) followed by Nitisols (19.7%). Mean annual rainfall in the region is over 1500 mm varying with altitude. Water levels in river Manafwa increased with rainfall and sometimes exceed 10.45 m with overflow and causing widespread floods in low lying areas. Pollution as measured by the turbidity of water in river Manafwa was highest during the rainy seasons. The observed average discharge of river into the wetland is 7.68 $m^3 s^{-1}$ with an average sediment concentration of 160 $g l^{-1}$. Runoff source areas were not necessarily the sediment source areas (about 0.1% of the catchment contributes 30% of the runoff) and most of the runoff contributing areas (moderate to high yield) are located in the western part of the catchment. Sediment source areas are located in the south-eastern part of the catchment and about 20% of the catchment generates 70% of the sediments in River Manafwa. The average annual sediment yields from different hydrological response units were found to be high ranging from 5.73 to 241 $Mg\ km^{-2}\ yr^{-1}$ with an average of 45 $Mg\ km^{-2}\ yr^{-1}$ while the average soil loss and runoff from the catchment is moderate and averaged 43 $t\ ha^{-1}yr^{-1}$ for sediments. Sediment deposition in the rice wetland was estimated at 5.07 $cm\ m^{-2}\ yr^{-1}$. Nitrogen use efficiency was found to be highly dependent on water management and fertilizer application. Fertilized plots had the highest N use efficiency (51.1%) compared to the control (13.7%). Nitrogen use efficiency decreased as less water is present in the rice wetland. Fertilizer application to rice wetlands increased grain yields by 40% with a benefit to cost ratio of 2.54 compare to unfertilized fields with benefit to cost ratio of 2.22. For river Manafwa, there was a clear pattern of enrichment of oxygen-18 and hydrogen-2 in downstream water attributable to selective evaporation of lighter isotopes as the conditions become warmer in lowlands.

1. INTRODUCTION

Identifying and understanding the dynamics of pollution sources, pathways and sinks are important pre-requisites for the sustainable management of fragile ecosystems [1]. The need for knowledge and information increased as a result of the impact of climate change on land and water eco-systems. The requirement for appropriate mitigation and adaptation measures to buffer the populations and the landscape resources against the adverse impacts (flooding, soil erosion and agricultural productivity) of climate change is high. In Uganda, most fragile ecosystems including wetlands and mountain in the Eastern part of the country, are undergoing various forms of conversions and environmental degradation, threatening the sustainability of livelihoods of population [2] The knowledge on the nexus between the mountain and wetland ecosystems is important for identifying appropriate intervention for the sustainable use of land and water resources in these regions.

There was limited understanding of the relationship between anthropogenic activities and the functions of rice wetland systems in Manafwa catchment. Often the activities and hydrological processes that take place in the upper reaches of the catchment affect the downstream water storage, nutrient availability and dynamics. Systemic knowledge of the sources and sinks of water (e.g. magnitude, frequency, duration, timing, rate of the water flow regimes, nutrient and their cycling into and out of the system as influenced by upland activities is essential for making decisions for selection of sustainable management practices of these systems for conservation and reuse of water and nutrients. The objective of the project was to quantify water fluxes through these wetland areas; and to determine the capacity of these wetlands for water storage, assess nutrient/pollutant attenuation capacity and to understand the link between water and nutrient dynamics in wetlands and rice production.

The specific objectives of the study were to assess (a) erosion magnitude in the upstream (b) sediment loading rates in the streams (c) deposition in the wetland, with a view of understanding retention capacities within the catchment, and (d) fertilizer use efficiency under wetland rice. This study focused on an interlinked mountain-wetland ecosystem. To achieve the general objectives of the project, the project was partitioned into four phases each phase covering a one year period which had specific objectives/activities though some of the activities were overlapping as they have not been completed within the timeframe. The study was carried out over a period of five years from December 2008 to August 2013.

2. METHODS AND MATERIALS

2.1. Location

The project was carried out at Sinje sub-catchment, Manafwa Catchment, Mount Elgon, Eastern Uganda. Geographically, the study area lies between 1°07'07"N, 34°13'07"E and 1°07'24"N, 34°31'22"E. Mt. Elgon is a trans-boundary ecosystems located in both Eastern Uganda and Western Kenya (Figure 1).

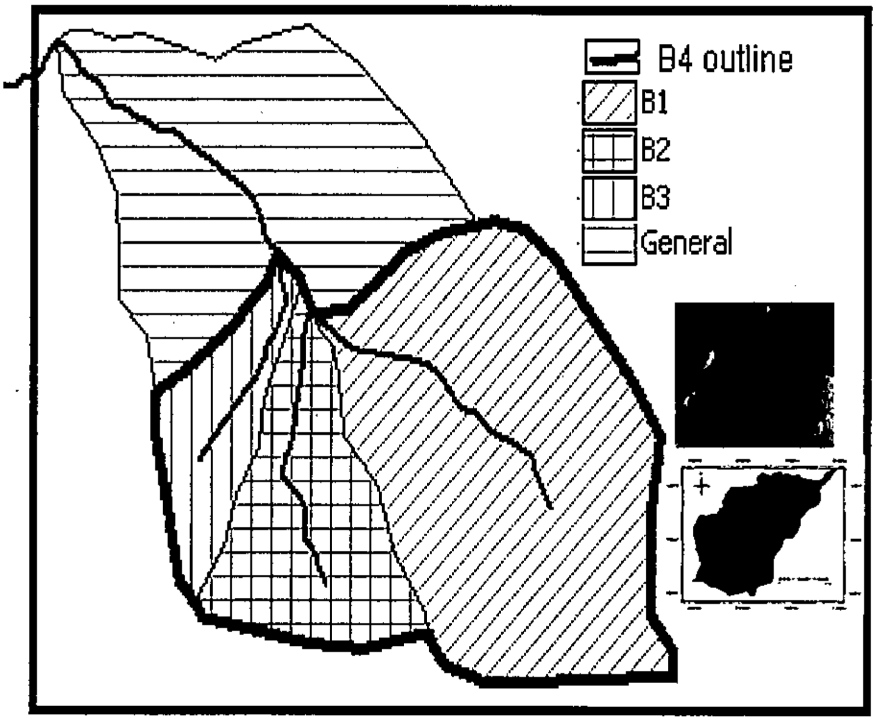

FIG.1. Location of the Sinje micro-catchment. Mt. Elgon and Manafwa Catchment are shown as inlets

The elevation of the catchment ranges from 1 240 to 1 560 m.s.l with a mean elevation of 1 401 m. The climate of Mount Elgon is classified as humid subtropical and is dominated by seasonally alternating moist south-westerly and dry north-easterly air streams. The rainfall distribution shows a weak bimodal rainfall pattern. Rainfall occurs between April to December, with June and July the lowest. Mean annual rainfall amounts over 1500 mm and is a function of altitude (Figure.2). The average minimum and maximum temperatures are 15 and 28^{0}C respectively for the catchment.

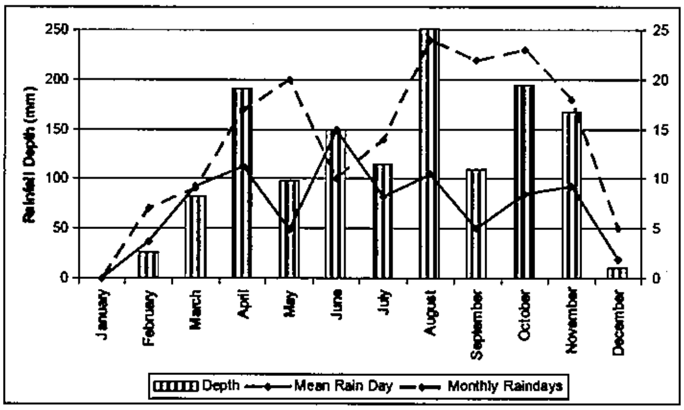

FIG. 2 Mean monthly rainfall total and rain days in 2007

2.2. Soil types and geology

According to the FAO classification the major soils of Manafwa catchment (Figure. 3) include *Nitisols (19.7%), Lixic ferralsols (33.3%), acric ferralsols (6.8%), petric plinthosols (29.3%),* and *gleysols(12.8%). Lixic ferralsols* in Manafwa is formed by the Bubutu and Bududa series and Tororo complex which are deeply weathered red or yellow soils derived from basement complex granites and/or Elgon volcanics. *Acric ferralsols* are represented by the Bubulu series and Mbale complex. These soils are red sand clay loam and occasionally laterized. The parent materials are Basement Complex mica schists/granites and amphibolites. *Nitisols* are represented by the Masaba, Bugusege and Benet series, and the Sipi catena. *Plintosols* are represented by Lwampanga series and Mazimasa complex and Buruli catena. The parent materials are lake deposits derived from/ and basement complex granites, gneisses, etc. The soils are reddish brown in colour, sandy loams and loams textured on laterite. *Gleysols* are basically peat or peaty sands and clays located in the valley.

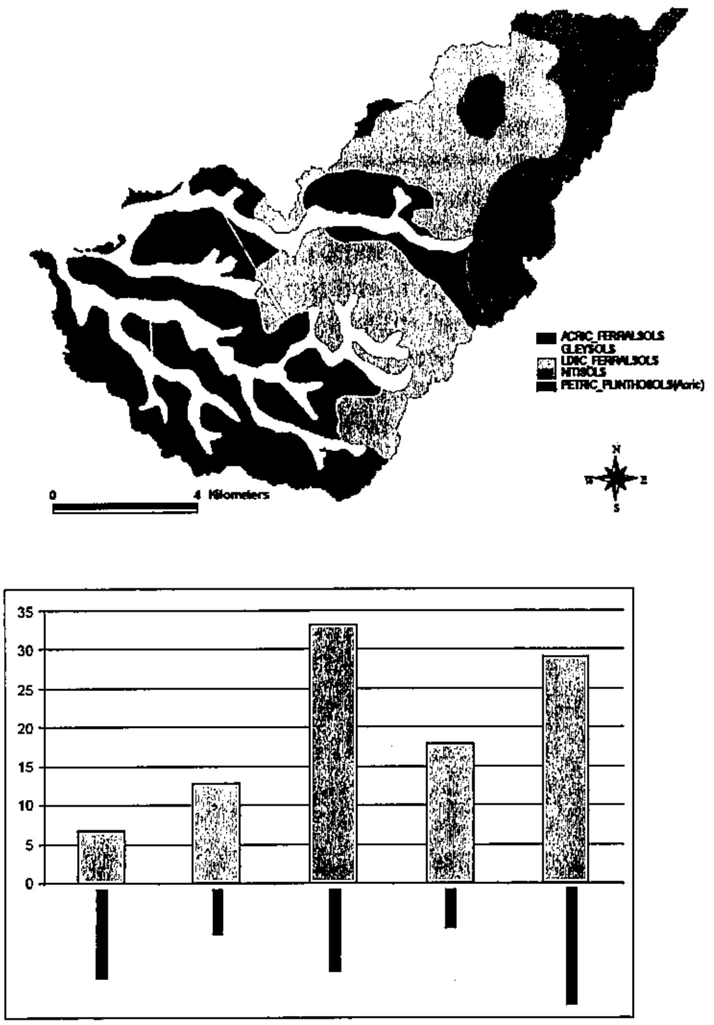

FIG. 3. Distribution of soil types and the area in Mount Elgon

2.3. Cropping systems and land use in the study area

The cropping system in the area reflects the montane farming system which is typical of Mt. Elgon with both annual and perennial crops. Many crops are grown owing to the climatic conditions and relatively fertile soils. The crops include coffee, banana, maize beans, potato, cassava, groundnut among others. Over 90% of the farmers practice intercropping due to land scarcity. There can be up to six intercrops on a single cropping field and annually there can be up to three crop cycles particularly for beans. The cropping and hydrological aspects from a baseline survey conducted in January 2009 are given in Table 1.

TABLE 1. DESCRIPTION OF SELECTED SITES AND LAND USES IN THE MANAFWA CATCHMENT

Location	Description
Wanende	• Rice and sugar cane are the major crops grown nearer the bank while maize and bananas appear the further one moves away from the banks. • Small stream wish water flowing at very low speed and cannot be used as source for domestic use unlike other locations • Base of stream is predominantly clay soil
Nambale	• Land use along the banks is mainly pasture land but with some scattered woodlots • The adjacent slopes have grazing land with some scattered shrubs at the middle slope and bananas at the bottom slopes
Mbale-Manafa district boundary	• A point where Manafwa district separates with Mbale • Land use is predominantly yams on one side and Eucalyptus woodlots on the other • Water level is similar to Wanende but stream base containing plinthic material instead
Manafa Bridge	• Intercrops of banana-coffee, bananas-cassava, sugarcane and vegetables such as cabbage, tomatoes are the mail crops grown • River shows evidence of flooding beyond permanent banks
Pasa junction	• Large tributary of R. Manafwa • Evidence of extensive sand extraction
Liso	• Also large tributary of R. Manafwa • Banks of streams mainly used for grazing with settlements in the further parts .
Bugumanai Bridge	• Settlements very close to the riverbank of the stream • The banks are sharp and deep ($\simeq$2 m)

2.4. Water Inflows and Outflows

The water inflows and outflows are marked by the source(s) and mouth(s) respectively of river Sinjė and its tributaries. To be able to quantify the contribution of a particular area within the watershed to sediment and nutrient loads, it is necessary to determine these parameters at the inflow and outflow points of the draining streams. For this reason, water samples were continuously be taken at the outlets of each tributary and at the mouth of river Sinje.

2.5. Field Measurements

2.5.1. Soil and water measurements

The monitoring of runoff and soil loss was undertaken at 12 geo-referenced sites within Sinje Sub-catchment. Geographical locations as well as the altitude of each site are given in Table 2. Four sites were used for monitoring total suspended solids (TSS) and discharge. These sites were also used for detailed monitoring and analysis of total nitrogen (TN) and total phosphorus (TP).

TABLE 2. LOCATIONS FOR RUNOFF AND SOIL LOSS MEASUREMENT

Site	GPS Reading	Altitude (M)	Slope Gradient (%)
1	0°59'05.06"N, 34°19'55.73"E	1280	32
2	0°59'04.15"N, 34°19'55.38"E	1289	32
3	0°58'55.16"N, 34°20'09.15"E	1318	24
4	0°59'09.88"N, 34°19'53.83"E	1268	22
5	0°59'26.36"N, 34°19'57.30"E	1259	14
6	0°59'26.84"N, 34°19'56.99"E	1259	12
7	0°58'56.82"N, 29°05'30.15"E	1287	31
8	0°59'05.29"N, 34°19'54.54"E	1290	31
9	0°59'21.37"N, 34°20'06.00"E	1269	27
10	0°59'21.37"N, 34°20'06.00"E	1279	26
11	0°58'54.02"N, 34°20'09.80"E	1318	13
12	0°58'53.76"N, 34°20'09.86"E	1309	14

2.5.2. Hydraulic conductivity of the wetland soils

The hydraulic conductivity of the soil of the wetland was estimated using the auger hole method, at three sites. An auger of 5 cm diameter was used to scoop soil in the wetland up to 2 m depth with minimum disturbance, and water was allowed to equilibrate with ground water table. The rate of water flow in the cavity was measured every minute up to equilibrium.

2.5.3. Erosion and sediment modeling

A GIS-based SWAT model has been used to simulate erosion and sediment patterns in Manafwa catchment [3]. The layers used in this simulation included: soil, land use/land cover, digital elevation model (DEM) and climate data. Soil data was obtained from the National Soils Laboratory at Kawanda; land use/land cover was clipped from the USGS data set; the DEM was generated from digitized contours of the area while climatic data was obtained from the Department of Meteorology. The model was calibrated using data observed from experimental plots as well as discharge data (1960-2009) obtained from the Directorate of Water Resources Management in Uganda.

2.5.4. Efficiency of N-fertilizer use in paddy rice experiment.

A factorial experiment was conducted in Doho rice scheme in the lower reaches of Manafwa catchment (Figure. 4). Two factors that include water management and nitrogen (N) fertilizer application were considered. The water management was at three levels namely: good, moderate and poor and two levels of N fertilizer application namely 120 kg/ha of urea (labelled with ^{15}N at 2% atom excess) and control with no fertilizer application (Table 3). Each treatment was replicated three times. Six micro plots each measuring 2 m^2, were for this purpose laid out randomly in 20 x 20 m^2 plots.

Parameters monitored in each plot include daily water levels, plant phonological characteristics, biomass and grain yields. At physiological maturity, sampling carried out for roots, shoot and un-milled rice grain. Soil samples were collected at two depths (0-15 and 15-30 cm) prior to planting and at harvest for N use efficiency determination (Table 3). The soil and plant samples were processed and sent to IAEA in Vienna, Austria for analysis of plant N, ^{15}N excess, plant C and ^{13}C. The fertilizer N use efficiency was calculated using the following equation [4];

$$\%Ndff = \frac{\%^{15}N\ atom\ excess\ of\ plant}{\%^{15}N\ atom\ excess\ in\ Fertilizer} \times 100 \qquad (1)$$

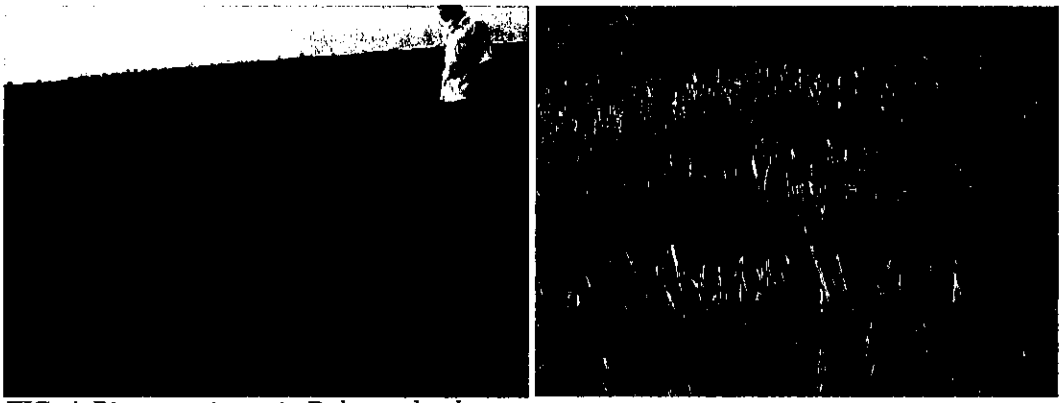

FIG. 4. Rice experiment in Doho wetlands

TABLE 3. SAMPLING FRAMEWORK FOR THE ISOTOPIC N-FERTILIZER USE EFFICIENCY EXPERIMENT IN PADDY RICE

Descriptor	**Treatment**
Rate of ^{15}N fertilizer application	120 kg N/ha (52g of ^{15}N urea for a 2m^2 plot), replicated thrice at three locations
Approx. 2% ^{15}N enrichment of urea fertilizer	To use the fertilizer directly as urea
Time of application of ^{15}N labelled fertilizer	At planting and tasseling (26 g of ^{15}N urea for a 2m^2 plot)
Time of harvest	At physiological maturity

2.5.5. *Water physico-chemical characterization (18O)*

The physico-chemical water characterization will cover 7 sites namely; River Manafwa upstream, River Manafwa Bridge, River Manafwa downstream entrance into Doho rice scheme, underground water, wetland water, Lake Kyoga water. Water samples were picked and taken for laboratory analysis at IAEA, Vienna, Austria.

2.5.6. *Economic benefit of rice growing in Doho*

The economic benefit analysis was done by considering production costs of rice that included the cost of planting materials, fertilizers, pesticides, transport, local fees and labor for planting, weeding, harvesting and processing) against the sell price of the produce. This information was obtained from three key informants. Yield data was obtained from the rice experiment that was conducted.

3. RESULTS

3.1. Chemical characteristics of soil and water

An analysis of soil chemical and physical properties at twelve monitoring sites showed that the mean values of Ca, K, Na, N, and SOM contents were higher in the 0-15 cm soil depth (Table 4 and Table 5). On the contrary, pH, Available P (Av. P) and Mg increased from 0-15 cm (top soil) to 15-30 cm (sub soil) soil depth (Table 4 and Table 5). Overall, pH ranged from 5.6 to 6.2 in the topsoil and 5.8 to 6.6 in the sub soil, all above the critical value; SOM varied from 2.2 to 3.7% in the top soil and 1.7 to 2.9% in the sub soil; N ranged from 0.14 to 0.21% and 0.1 to 0.18% in the upper and bottom soils respectively and these values were below the critical value. Consistently, Av. P had a higher site variation with the two soil depths. It varied 17 and 33 times from 1.1 to 18.3ppm and from 0.61 to 20ppm in the top soil and sub soil respectively. Similarly, K varied but five times from 0.34 to 1.81 C mol kg^{-1} in the top soil and six times from 0.23 to 1.47 C mol.kg^{-1} in the sub soil while Na in the topsoil varied 12 times ranging from 0.03 to 0.36 C mol kg^{-1} and seven times from 0.04 to 0.28 C mol kg^{-1}in the bottom soil. Like all the nutrients so far mentioned, Ca also varied though three times from 3.3 to 9.5 C mol kg^{-1} in the topsoil and four times from 3.74 to 13.2 C mol kg^{-1} in the sub soil and Mg in the top soil ranged from 0.69 to 3.65 C mol kg^{-1} varying five times, while in the sub soil, it varied three times from 1.26 to 3.74 C mol kg^{-1}.

For the physical properties, sand and silt had greater values in the topsoil. Conversely, the mean clay content was greater in the sub soil. The sand content ranged from 25 to 34% in the top soil and 18 to 32% in the sub soil; silt varied approximately three times from 10 to 26 in the top soil and approximately two times from 15 to 26 in the sub soil; clay varied from 42 to 64% in the top soil, while in the sub soil, it ranged from 43 to 58%.

TABLE 4. SOIL PHYSICAL AND CHEMICAL CHARACTERISTICS FOR 0-15 CM LAYER (0-15CM)

Statistic	pH	Av.P	Ca	K	Mg	Na	N	SOM	Sand	Silt	Clay
		ppm	----------- $cmolkg^{-1}$ -----------				----------------- % -----------------				
N	12	12	12	12	12	12	12	12	12	12	12
Mean	6	6.8	5.8	0.87	2	0.18	0.17	2.9	29	20	51
Median	5.9	5.8	5.6	0.76	2.18	0.15	0.17	2.83	29	20	50
Minimum	5.6	1.1	3.3	0.34	0.69	0.03	0.14	2.21	25	10	42
Maximum	6.2	18.3	9.5	1.81	3.65	0.36	0.21	3.67	34	26	64
Range	0.6	17.2	6.2	1.47	2.96	0.33	0.07	1.46	9	16	22
STDEV	0.18	5.63	2	0.42	0.95	0.1	0.02	0.37	2.8	4.32	5.48
SE	0.05	1.62	0.58	0.12	0.28	0.03	0.01	0.11	0.81	1.25	1.58
C.V (%)	3	82.5	34.6	48.6	46.8	57.7	12.5	12.6	9.64	21.5	10.8
Skewness	-0.2	0.7	0.57	0.82	0.08	0.28	0.18	0.28	0.23	-0.81	0.98
Kurtosis	-0.6	-0.61	-0.6	0.05	-1.08	0.36	-0.7	0.36	-1.01	0.54	1.09

TABLE 5. VARIATION OF SOIL PROPERTIES IN THE SUB SOIL (15-30CM)

Statistic	pH	Av.P	Ca	K	Mg	Na	N	SOM	Sand	Silt	Clay
		ppm	----------- c mol kg^{-1} -----------				----------------- % -----------------				
N	12	12	12	12	12	12	12	12	12	12	12
Mean	6.1	7.2	5.8	0.52	2.12	0.13	0.15	2.28	26.2	21	52
Median	6.1	5.8	4.8	0.44	2.0	0.14	0.15	2.28	26	22	54
Minimum	5.8	0.61	3.7	0.23	1.26	0.04	0.10	1.70	18	15	43
Maximum	6.6	19.9	13.2	1.47	3.74	0.28	0.18	2.90	32	26	58
Range	0.80	19.3	9.5	1.24	2.48	0.24	0.08	1.2	14	11	15
STDEV	0.24	6.14	2.7	0.34	0.67	0.07	0.02	0.36	4.5	3.1	5.2
SE	0.07	1.80	0.77	0.10	0.19	0.02	0.01	0.11	1.3	0.90	1.5
C.V (%)	4.0	85.7	45.6	64.7	31.6	51.0	14.2	16	17.1	15	10
Skewness	0.62	0.82	1.9	2.2	1.2	0.71	0.88	0.004	-0.26	-0.29	-0.45
Kurtosis	-0.3	-0.43	3.0	3.7	0.97	0.71	0.64	-0.99	-0.98	-0.36	-1.28

SE: Standard Error, STDEV: Standard Deviation

3.2. Characteristics of water

Results of chemical and physical characteristics of water for the period from 2008 to 2010 are provided in Table 6. The highest turbidity was recorded in March of 2010 followed by August of 2008 and May of 2009. The lowest was observed in December 2008 followed by March 2009 and lastly, January 2010. Highest and lowest pH values were observed in the month of September and August 2009 respectively. Alkalinity was found to be highest in the month of September and lowest in October of 2008. Highest and lowest color value was observed in the month of August and March of 2009 respectively.

TABLE 6. MONTHLY MEAN VARIATION OF PHYSICO-CHEMICAL PARAMETERS OF RIVER MANAFWA IN 2008-2010

Month	Turbidity (mg/l)			Color (pt)	Alkalinity (mg/l)	pH	Total rainfall (mm)	
	2008	2009	2010	2009	2008	2009	2009	2010
January		24	280	478			85	60
February		41	408	139			33	286
March		21	704	88			97	274
April		246	673	1068			277	103
May		417	525	1427			299	199
June		119		481			43	23
August	583	347		866	64	6.5	65	
September		356			464	7.1	80	
October	413	411			64	6.8	136	
November	323	350			75	6.9	195	
December	19	226			100	6.8	302	

The average water level in the river was highest (10.45 m) in May, 2010 with total rainfall of 199 mm (Table 7). However, during late February and March, 2010, the river flooded and destroyed most of the crops and other properties along the bank. Average water level and rainfall during these months was 9.95 m, R/F 285.5 mm and 10.284 m, R/F 273.5 mm respectively. Rainfall was recorded highest in February (285.5 mm). Average water level increased with rainfall except in the Month of May, 2010 where rainfall was low with high water level (Table 7).

TABLE 7. WATER LEVEL VARIATIONS IN RIVER MANAFWA AT MBALE – TORORO BRIDGE

Days	Jan	Feb	Mar	April	May	June
	Daily water level meters					
1	10.52	9.65	11.62	10.31	10.43	10.18
2	10.29	9.65	11.72	10.25	10.42	10.13
3	10.35	9.65	11.18	10.52	10.26	10.12
4	10.08	9.74	10.87	10.28	10.21	10.10
5	10.06	9.74	10.85	10.23	10.27	10.12
6	10.14	9.75	10.72	10.15	10.36	10.11
7	10.28	9.77	10.44	10.07	10.37	10.08
8	9.99	9.77	10.39	10.01	10.37	10.19
9	10.58	9.75	10.32	9.98	10.37	10.11
10	11.18	9.67	10.22	9.93	11.20	10.04
11	10.19	9.6	10.14	9.89	11.03	9.94
12	10.45	9.60	10.05	9.99	11.75	9.96
13	10.12	9.60	10.02	9.96	10.77	9.96
14	10.02	9.6	9.99	9.96	10.55	10.25
15	9.89	9.6	9.95	9.99	10.49	10.53
16	9.79	9.6	9.94	10.20	10.78	10.21
17	9.79	9.69	9.91	10.08	10.51	10.25
18	9.77	9.67	9.91	10.07	10.43	10.23
19	9.76	9.61	9.90	10.34	10.27	10.14
20	9.76	9.61	9.96	10.25	10.25	10.03
21	9.81	9.94	9.95	10.22	10.18	9.99
22	9.89	9.98	9.94	10.20	10.22	9.96
23	9.81	11.17	9.94	10.13	10.23	9.94
24	9.77	10.32	10.02	10.22	10.52	9.91
25	9.74	10.06	10.01	11.13	10.29	9.98
26	9.69	12.15	10.02	10.47	10.18	9.93
27	9.65	11.53	10.2	10.27	10.22	9.89
28	9.64	10.18	10.2	10.18	10.23	9.89
29	9.64		10.04	10.12	10.22	9.89
30	9.63		10.03	10.15	10.13	9.93
31	9.63		10.43		10.30	
Average	9.99	9.95	10.28	10.18	10.45	10.07
Total	60	285.5	273.5	103	199	23

The results indicated that high turbidity in the rainy seasons is due to surface runoff carrying dissolved organic matter and other soil particles. In 2009, the high rainfall was recorded in the months of April to May and October to December and during these periods the turbidity was high. In 2010, high rains were recorded in the months of February to May. However, turbidity was highest in the year of 2010 due to highest rainfall received compared to 2009 during the months of February to May and average water level was highest during those months in the year 2010. During the period of short or no rains, turbidity decreased.

The pH value of the river was observed to be slightly acidic to slightly alkaline in nature with small variation in the year of 2009 during the period of data collection. The highest pH was (7.14) in September. The highest and lowest alkalinity values were all above 40mg/l hence this water is considered to have hard water characteristics, which helps to maintain the pH value in a slightly alkaline conditions. Water color showed a positive correlation with rainfall (R^2= 0.67). Water color increased with increase in rainfall and the highest color value (1 427.9 pt) was recorded in May which had the highest rainfall (299.2 mm) during the period of water color data collection in the year 2009. There was a strong correlation among turbidity, color and rainfall (R^2 = 0.85). High rainfall in the Month of May of the year 2009 led to high turbidity and color.

3.3. Hydraulic conductivity of the wetland soils

Results from hydraulic conductivity measurements showed that water table was at 120 cm below the soil surface in March and hydraulic conductivity was of 2.5 cm/h (0.016 m/yr); insinuating that the sub-soil was mainly clayey.

3.4. Characteristics and classification of the wetland

Table 8 and Table 9 showed wetland characteristics which vary with depth; at the time of soil profile description, the soil was moist and five horizons were described ranging from 0 - 180 cm in depth. The dominant soil color of the different horizons is dark grey with black color at the surface. The wetland has mottles which are fine in size and range from distinct in prominence at the surface layers to prominent in the deeper layers. The major soil type in the wetland is clayey and the soil structure in the wetland is graded as moderate at the surface to strong at the deeper horizons in terms of its development hence the soils are well developed. In terms of size, the structure ranges from coarse to very coarse as the depth increases and the structure is mainly sub-angular blocky.

TABLE 8. CHARACTERISTICS AND CLASSIFICATION OF THE WETLAND

Slope %	0
Topography	Flat
Micro relief	0
Water table	170 cm
Root outcrop	0
Water erosion	0
Gravel	0
Soil drainage class	V
Grazing	0
Cultivated	Yes
Crops at site	Fallow
Crops within the hectare	Rice

TABLE 9. DEPTH CHARACTERISTICS OF WETLAND SOILS

Soil Depth (cm)		0- 15	15-30	30-55	55-108	108-180 +
Moisture status		moist	moist	moist	moist	Wet
Colour		5YR 2.5/1	7.5YR 3/2	10YR 3/1	10YR4/1	10YR4/1
Colour code		BL	DB	VDG	DG	DG
Mottles	Absence	Moderate	Moderate	moderate	few	few
	Size	fine	fine	fine	fine	coarse
	Prominance	distinct	Few	few	few	prominent
	Colour code	DYB	DYB	DG	DRB	Black
Texture		SCL	ZC	SCL	C	C
Consistence	Moist	FR	FI	VFR	FI	0
	Wet	S (SP)	SS (NP)	NS (NP)	S (SP)	NS (P)
Structure	Development	M	S	W	S	S
	Size	Coarse	VC	VF	Coarse	VC
	Type	SAB	SAB	SAB	SAB	AB
Clayskins	Absence	0	0	0	Few	Common
	Prominanace	0	0	0	few	prominent
Distinct pressure faces		0	0	0	0	0
Distinct shiny ped faces		0	0	0	0	M
Cracks		0	0	0	3 mm	0
Pores	Absence	MMM	MFM	MMM	F0M	F0F
	Size	FMC	FMC	FMC	F0C	F0C
Mineral nodule	Absence	0	0	0	FEW	0
	Size	0	0	0	Fine	0
	c-conc,s-seg	0	0	0	S	0
	Type	0	0	0	FM	0
Distinct Fe-induration		0	0	0	0	0
Roots	Absence	MM0	M00	FF0	F00	F00
	Size	FM0	F00	FM0	F00	F00
Horizon boundary		distinct and wavy	Smooth and gradual	Distinct and wavy	CS	

Note; YR-Yellow red, DYB-Dark yellow black, SCL-Sandy clay loam, ZC-Silt clay, C-Clay, FR-Friable, VFR-Very friable, FI- Fine , VC-very coarse, VF-very fine, SAB-Sub angular blocky, AB-Angular blocky, MMM, Moderate, MFM- Moderate few moderate, F0M- Few none moderate, FOF- Few none few, FOC- Few none common, FMC- Few moderate common, FM-Few moderate, V- Very poorly drained, BL-Black, DB-Dark brown, VDG- very dark greyish, DG-Dark greyish, DRB-Dark red brown

3.5. Spatially modelled patterns of erosion and sediment loading in Manafwa catchment Runoff and sediment hotspot areas

The observed discharge (1960-2005) when entering the wetland ranges between 3 m^3/s (base flow) and 25 m^3/s (peak flow); with an annual average was of 7.7 m^3/s. The simulated discharge ranged from 3 m^3/s to 28 m^3/s, with an average of 10 m^3/s (Figure 5); the simulated average concentration of sediment was 160 g/l equivalent to 260 ton/day. Runoff and soil loss hotspots from Manafwa catchment showed that runoff source areas are not necessary sediment source areas (Figure 6 and Figure 7). Ten square kilometers (about 0.1% of the catchment) is contributing 30% of the runoff in the catchment. Most of the runoff contributing areas (moderate to high yield) are located in the western part of the catchment. Sediment source areas are located in the south-eastern part of the catchment. Twenty percent of the catchment generates 70% of the sediments in the catchment.

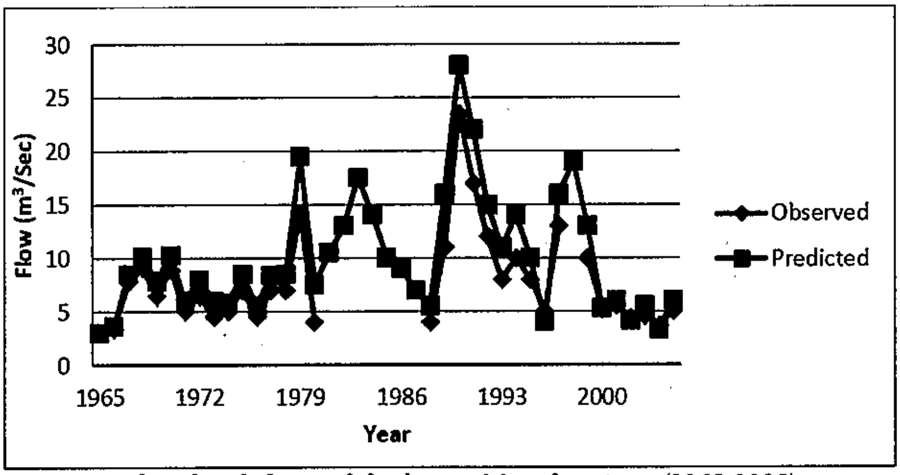

FIG. 5. Predicted and observed discharge, Manafwa river (1965-2005)

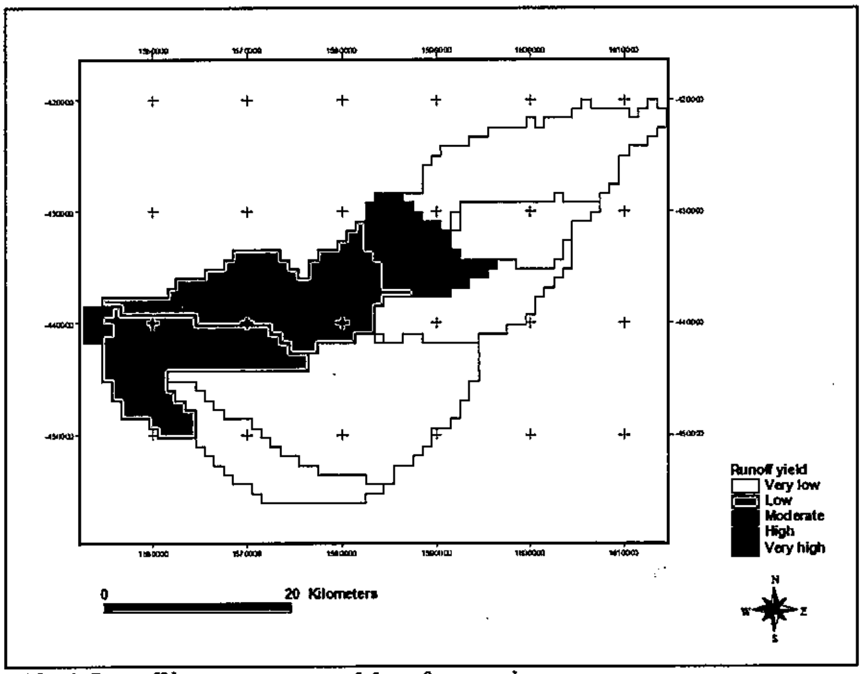

FIG. 6. Runoff hotspot areas in Manafwa catchment

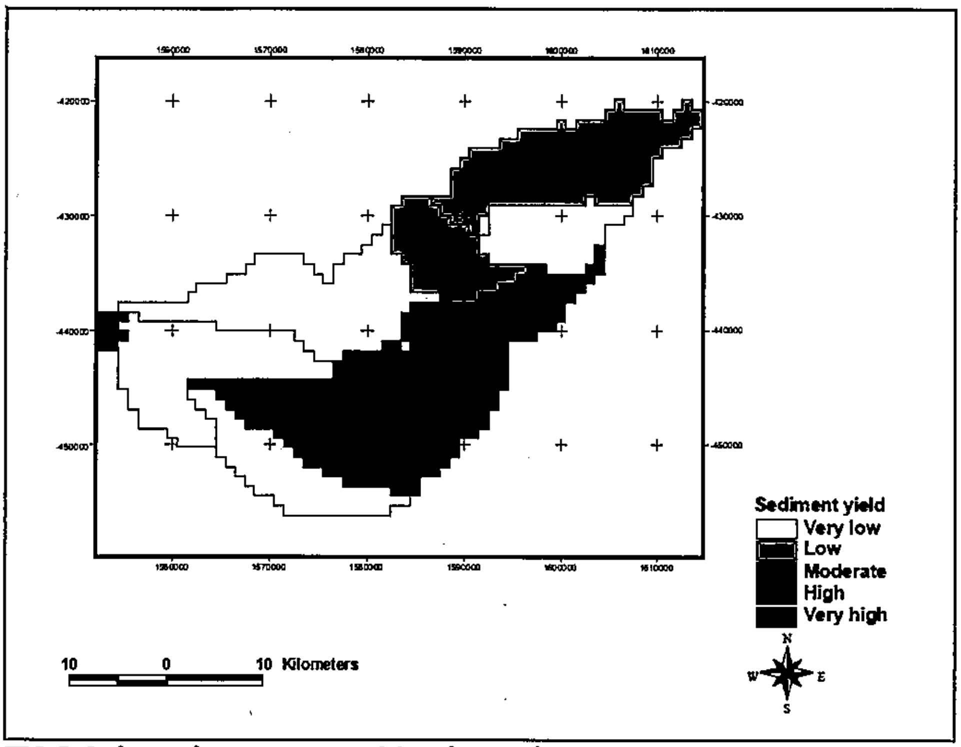

FIG 7. Sediment hotspot areas in Manafwa catchment

The average annual sediment yields from different hydrological response units are ranging from 5.7 to 241 Mg km^{-2} yr^{-1} (average of 45 Mg km^{-2} yr^{-1}) which is relatively high compared to other catchments in Uganda [5], though comparable to published values for other undisturbed tropical catchments (e.g. [6];[7]). If the 241 Mg km^{-2} yr^{-1} generated by the 10 km^2 is excluded the average annual sediment yield fall to 18 Mg km^{-2} yr^{-1} which is slightly closer to other sediment yields in Ugandan catchments. The ten km^2 is covered by mostly sandy soil at the outlet of the catchment. The average soil loss and runoff losses from the catchment is moderate and averaged 43 t/ha/yr for sediments and 135 m^3 ha^{-1} yr^{-1}. This insinuates that sediments found in suspension in river Manafwa are not from interill and rill erosion only, but might also be coming from gullies, river bank erosion and landslide areas. Manafwa catchment count the highest number of landslide scares among Uganda's catchments. From 98 recent landslides mapped it was estimated that about 11 million m^3 of slope material have been displaced in Manjiya county ([8];[9];[10]).

Manjiya County, within the Mbale district and situated on the southwestern footslopes of Mount Elgon, is the most sensitive area for landslides in Uganda [11]. Mass movements associated with intense rain-storms are reported to have occurred periodically in Manjiya since the early 20th century but the increase in fatalities and losses as a consequence of the enormous population growth draws attention to the phenomenon [9].

3.6. Sedimentation of wetlands

Information obtained through field observation in the study area showed that half of the volume of water abstracted from the river through the wetland on a daily basis. Assuming that the sediment concentration of the abstracted water is similar to that of the main river, the wetlands received about 130 ton/day of sediment (13.7 $kg/m^2/yr$). This represents a sediment accumulation of 5.07 $cm/m^2/yr$. There is need; however, to estimate for a relatively long time the quantity of water deviated by rice farmers at Doho.

3.7. Potential impact to the wetland

Suspended sediments in water alter water quality, primary productivity, and invertebrates in aquatic ecosystems [12]. Suspended sediment reduces light penetration and reduces the rate of photosynthesis [13] and covers substrates critical to the production of periphytic algae and macrophytes. Critical sediment depth goes up to 0.25 cm for significant reduction of species richness, emergence, and germination of wetland macrophytes ([14];[15]). Wetland water depth reduction might also result in the development of monotypic stands of vegetation that provide little biological diversity and exacerbate problems with farmers for soil and water management.
Sediment effects on primary production translate into impacts on organisms at higher trophic levels through the aquatic food chain. Declines in algal production, loss of standing vegetative structure [16], and covering of organic matter [17] make wetlands less productive of invertebrates through the indirect loss of forage and habitat. Direct effects include covering of invertebrates and their eggs, and clogging of filtering apparatuses. High levels of silt and clay also are toxic to zooplankton and/or reduce feeding rate and assimilation, thus reducing energy available for reproduction [18]. Aquatic invertebrates play critical roles in wetlands to facilitate nutrient cycling [19] and are required foods for wildlife ([20];[21]).

3.8. Nitrogen uptake and efficiency

Nitrogen use efficiency was dependent on water management and fertilizer application ($P<0.001$), and the interaction between water management and fertilizer application was also statistically significant ($P=0.019$). Fertilized application had the highest N use efficiency (51.1%) compared to the control (13.7%) (Figure 8). N use efficiency decreased as water management decreased (Figure 9).

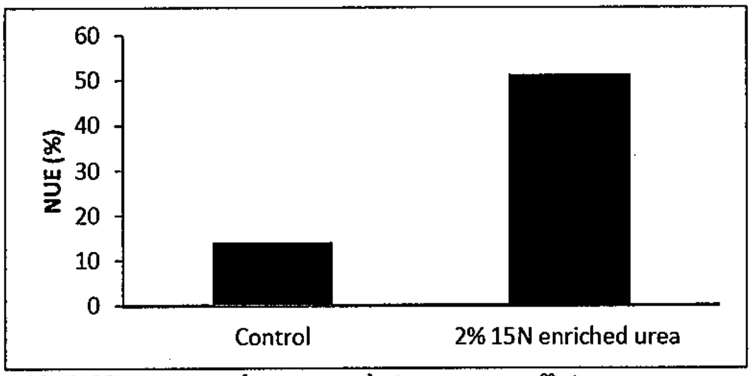

FIG. 8. Nitrogen application and nitrogen use efficiency

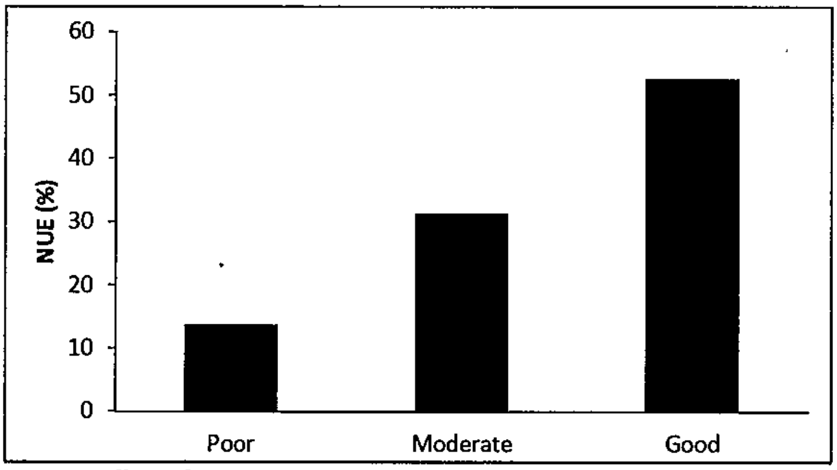

FIG. 9. Effect of water management on nitrogen use efficiency, in Doho Rice Scheme

Table 8 shows the concentration of nitrogen in the different vegetative part of the rice crop under control (no N application) and 2% ^{15}N enriched with urea application. The concentration of N in all the different part of rice (grain, root and shoot) was higher under plots which had received 2% 15N enriched with urea treatment ($P<0.01$); except in the upper zone for root and shoot. As for the NUE, water management had a significant effect on the nitrogen concentration for the different parts of the rice crop ($P\leq 0.05$). Water management had a positive effect on nitrogen concentration in rice.

TABLE 9. CONCENTRATION OF NITROGEN GRAIN, ROOT AND SHOOT OF RICE, IN DOHO RICE SCHEME

Water management	**Treatment**	**Grain** %	**Root**	**Shoot**	**Plant**
	Control	0.013	0.015	0.020	0.048
Poor	*2% 15N enriched urea 15N*	0.47	0.013	0.014	0.497
	Control	0.007	0.009	0.014	0.029
Moderate	*2% 15N enriched urea 15N*	0.523	0.211	0.479	1.213
	Control	0.007	0.239	0.500	0.747
Good	*2% 15N enriched urea 15N*	0.511	0.271	0.572	1.354
LSD (≤0.05)	Treatment	*0.124*	*0.051*	*0.204*	*0.252*
	Location	*0.101*	*0.042*	*0.167*	*0.206*
	Location*Treatment	*0.175*	*0.072*	*0.289*	*0.357*

3.9. Nitrogen content in soils

As expected, plots that received ^{15}N labelled fertilizer were enriched with urea (Figure 10) suggesting that applied fertilizer remained in the soil after harvest

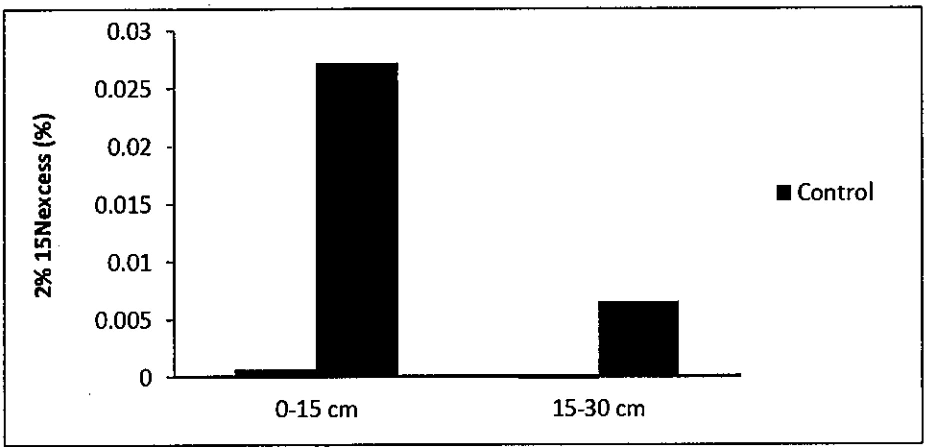

FIG 10. Applied N content (^{15}N) in control and fertilized plots

N content: Nitrogen content varied with water management and soil depth (Table 10) ($P \leq 0.05$). Plots that had moderate water management had lowest N content. As expected top soils had higher N content than the sub-soils for poor and moderate water management categories.

TABLE 10. NITROGEN CONTENT FOR THE DIFFERENT WATER MANAGEMENT CATEGORIES AND AT 0-15 CM AND 15-30 CM SOIL DEPTH

Water management	Soil N content (%)	
	0-15 cm	15-30 cm
Poor	0.3911	0.3651
Moderate	0.2982	0.2536
Good	0.4142	0.4098

Nitrogen application and soil water management were the key drivers of rice yield, N uptake, transport and transformations of N in the soil. These results corroborates with earlier findings ([22;23;24]). Nitrogen losses may increase due to the alternation of aerobic and anaerobic soil conditions ([25].

3.10. Grain and biomass yields from different applications

Table 11 shows the grain (un-milled and milled) and biomass yield in rice field trials conducted in Doho rice wetlands that receive water from Manafwa river. The grain yield both milled and un-milled. Both biomass and grain yield increased in fertilized plots compared to unfertilized plots.

TABLE 11. BIOMASS AND GRAIN YIELD IN DOHO RICE WETLANDS

Treatment	Un-milled grain yield (ton/ha)	Milled grain yield (ton/ha)	Biomass (ton/ha)
Fertilizer	7.67	3.6	24.59
No fertilizer	6.15	2.9	19.77

^{15}N isotopic signatures of rice grain and shoot showed that water management practices affected the amount of fertilizer N taken up by the rice crop, ranging from 34.6 kg N ha^{-1} under poor water availability to 57.7 kg N ha^{-1} under permanent water availability (Figure 5).
At the end of rice growing season, less than two percent of fertilizer N was present in the top 30 cm soil depth suggesting possible N losses through leaching, denitrification and volatilization. The rice wetland removed more than 70 percent of the applied fertilizer. The wetland rice production provided a minimum net economic return of US$1 300 per ha per cropping season.

3.11. Rice cultivation economic return in Doho

The economic return (ha) due to rice cultivation is given in Table 12 for fertilized and un fertilized rice plots. Weeding, water maintenance, harvesting and processing take 60% and 65% of total cost of rice production in fertilized and un fertilized rice plots; respectively. This is followed by the land preparation and transplanting cost. Fertilized plots (benefit to cost ratio=2.54) attracted more profit than the un-fertilized plots (benefit to cost ratio=2.22). The difference of profit per ha of land was estimated to 497 USD per season; representing a loss of 337,960 USD per annum to Manafwa catchment for not applying fertilizer for rice producton.

TABLE 12. GROSS MARGIN PER HECTARE OF RICE CULTIVATION IN MANAFWA CATCHMENT

*Input	Costs (Ugshs)	
	Fertilized	**Un fertilized**
Seed	96000	96000
Chemical fertilizers and agrochemicals	422400	192000
Land preparation and transplanting	547200	547200
Weeding, water maintenance, harvesting & processing	1704000	1704000
Land tax and interest	60000	60000
Crop yield (Kg/ha)	3592	2880
Total variable costs	2829600	2599200
Gross revenue from grain production	7184000	5760000
Net profit	4354400	3160800
Benefit to cost ratio	**2.54**	**2.22**

**one US$ is equivalent to 2400 Ugandan Schilling (Ugsh).*

3.12. Stream water pollution assessment using 18O isotopic analysis

Figure 11 showed the ^{18}O analysis for the water samples taken along R. Manafwa. There was a gradual increase in the isotopic signatures of both $\delta^{18}O$ and δD along river Manafwa from the mountain to low lands. There was a spontaneous rise in both $\delta^{18}O$ and δD as the river flows towards the lake. At this stage $\delta^{18}O$ moved from negative to positive values.

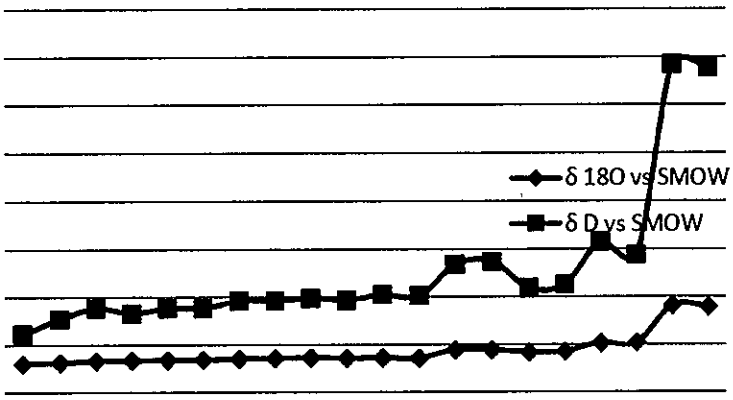

FIG. 11. ^{18}O and ^2H signatures of water along R. Manafwa

River Manafwa flows from the mountains downwards, the conditions become warmer and the water gets more evaporated resulting in enrichment in heavy stable isotopes (O-18 and D). The lighter isotopes tend to evaporate as the conditions get warmer leaving the heavy isotopes in the water. As the water gets evaporated and becomes more enriched in heavy isotopes, its isotopic signature becomes more and more positive as evidenced by both O-18 and D increasing and becoming more positive. The big increase occurs as the river flows to the Lake due to the fact that river water flows fast and is not very much evaporated compared to lake that is more stagnant and hence more exposed to evaporation (lake water is much more enriched in heavy isotopes than river water and that is the reason why it is much more positive than river water).

Isotopic signatures of $\delta^{18}O$ and δD are plotted against each other for water from the River Manafwa and the relationship ($\delta D=4.4593\ \delta^{18}O+10.612$, $R^2=0.9899$) is shown in Figure 12. The slope of the relationship is lower than both the African meteoric water line-AMWL, ($\delta D=7.4\delta^{18}O+10.1$, $R^2=1$) and Global meteoric water line-GMWL ($\delta D=8\delta^{18}O+10$, $R^2=1$). The waters of River Manafwa, the sample data are plotted in space together with the Global meteoric water line-GMWL and African meteoric water line-AMWL due to extreme continentally of rainfall in interior Africa.

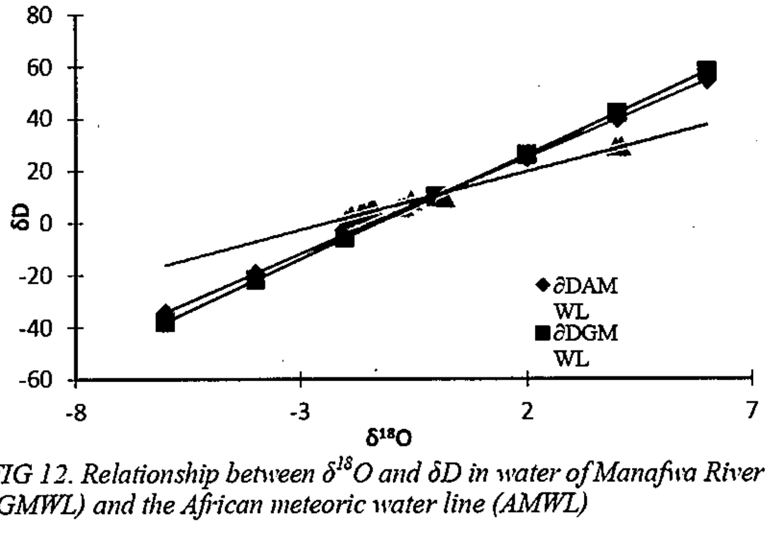

FIG 12. Relationship between $\delta^{18}O$ and δD in water of Manafwa River with global meteoric water line (GMWL) and the African meteoric water line (AMWL)

Figure 12 showed that the isotopic signatures of river water in a majority of location lie above the GMWL and the AMWL. The results showed that the river water receive sufficient input of water from the mountain to compensate evaporation.

4. CONCLUSIONS

The cropping system in the Manafwa catchment reflects the montane farming system which is typical of Mt. Elgon with both annual and perennial crops. Many crops like coffee, banana, maize beans, potatoes, cassava, and groundnuts among others are grown owing to the conducive climatic conditions and relatively fertile soils; and over 90% of the farmers practice intercropping understandably due to land scarcity. The major land use in the Manafwa micro catchment is small scale farming (84.8%) followed by degraded tropical forest (4.05%) and woodland (3.5%).

The observed mean content values of Ca, K, Na, N, and SOM were higher in the topsoil and on the contrary, pH, Av. P and Mg increased with soil depth. The range soil depth values of pH, SOM and N were smaller than the range values of other chemical soil properties. Overall, pH ranged from 5.6 to 6.2 in the topsoil and 5.8 to 6.6 in the bottom soil; SOM varied from 2.2 to 3.7% in the topsoil and 1.7 to 2.9% in the lower soil depth; N ranged from 0.14 to 0.21% and 0.1 to 0.18% in the upper and bottom soils respectively in the catchment. Sand and silt had greater values in the topsoil (0-15 cm). Conversely, the mean clay content was greater in the lower soil depth (15-30cm). The sand content ranged from 25 to 34% in the topsoil and 18 to 32% in the bottom soil; silt varied approximately three times from 10 to 26 in the upper soil and two times from 15 to 26 in the bottom soil; clay varied from 42 to 64% in the topsoil, while in the bottom soil, it ranged from 43 to 58%. The water table was at 120 cm below the soil surface in March and hydraulic conductivity was of 2.5 cm/h (0.016 m/yr); insinuating that the sub-soil was mainly clayey

Physical and chemical parameters of water were varied over time. The highest turbidity was recorded in March of 2010 followed by August of 2008 and lastly, May of 2009. The lowest was observed in December 2008 followed by March 2009 and lastly, January 2010. Highest and lowest pH values were observed in the month of September and August 2009 respectively. Alkalinity was found to be highest in the month of September and lowest in October of 2008. Highest and lowest color value was observed in the month of August and March of 2009 respectively. And the highest average monthly water level was 10.45 m in May, 2010 with total rainfall of 199 mm.

The observed discharge (1960-2005) when entering the wetland ranged between 3.03 m^3/s (base flow) and 25 m^3/s (peak flow); with an annual average was of 7.68 m^3/s while the simulated discharge ranged from 3.04 m^3/s to 28 m^3/s, with an average of 10.04 m^3/s; the simulated average concentration of sediment was 160 g/l equivalent to 260 ton/day. Runoff source areas are not necessary sediment source areas. Ten km^2 (about 0.1% of the catchment) is contributing 30 % of the runoff in the catchment. Most of the runoff contributing areas (moderate to high yield) are located in the western part of the catchment. Sediment source areas are located in the south-eastern part of the catchment. Twenty percent of the catchment generates 70 % of the sediments in R. Manafwa. The average annual sediment yields from the different hydrological response unit are ranging from 5.73 to 241 Mg km^{-2} yr^{-1}, averaged 45 Mg km^{-2} yr^{-1}

Environmental effects due to the wetland cultivation included; Increased incidences of pests and diseases like rodents, birds , rice yellow mottle virus, high incidence of blast,soil fertility decline due to persistent cultivation of the crop, Excessively low temperature which only favors one variety of rice (Shakti variety) to perform very well than others, Prevailing weeds especially http://en.wikipedia.org/wiki/Eudicot *Striga hermonthic,* Mono cropping without rotation affects nutrient replenishment, Planting three times a year leads to over exploitation of the nutrients, Application of mineral fertilizers affects water quality in the wetland and subsequently the diversity and abundance of the resident flora and fauna, Flooding of water in the rice scheme reduces stream flow to L. Kyoga, and Propagation of rice pests and diseases due to continuous planting of same crop season after season.

Fertilized plots had the highest N use efficiency (51.1%) compared to the control (13.7%) and N use efficiency decreased as water management deteriorates. The concentration of N in all the different part of rice (grain, root and shoot) was higher under plots which had received 2% 15N enriched with urea treatment ($P<0.01$); except in the upper zone for root and shoot. Water management had a significant effect on the nitrogen concentration for the different parts of the rice crop ($P\leq0.05$) and water management had a positive effect on nitrogen concentration in rice.

Carbon content only varied with water management and moderately managed plots had the lowest carbon content ($P<0.001$). 2% 15N enriched with urea excess was highest on plots were the fertilizer had been applied. Nitrogen content varied with water management and soil depth ($P\leq0.05$). Top soils had higher N content than the sub-soils for poor and moderate water management categories. Nitrogen application and soil water management were the key drivers of N uptake, transport and transformations of N in the soil.

For the economic return (ha) due to rice cultivation, weeding, water maintenance, harvesting and processing take 60% and 65% of the total cost for a fertilized and not fertilized rice garden; respectively, followed by the land preparation and transplanting cost. Fertilized garden (benefit to cost ratio=2.54) attracted more profit than the un-fertilized garden (benefit to cost ratio=2.22). The difference of profit per ha of land was estimated to 497 USD per season; representing a loss of 337,960 USD per annum to Manafwa catchment for not using fertilizers.

The ^{18}O analysis for the water samples taken along R. Manafwa showed a gradual increase in both $\delta^{18}O$ vs SMOW and δD vs SMOW as R. Manafwa flows from the mountains up to the low lands. There was a spontaneous rise in both $\delta^{18}O$ vs SMOW and δD vs SMOW as the river flows towards the lake. At this stage $\delta^{18}O$ vs SMOW moved from negative to positive values.

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