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Original Article

Characterizing River Manafwa Floodplain and Adjacent Soils

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ABSTRACT

The objective of this study was to characterise Manafwa River floodplain and adjacent soils. Soil samples were collected from 0 - 20 cm depth in fallowed and cultivated Manafwa floodplain soils for laboratory analysis. Treatments included upland (control), floodplains fallowed for a year, floodplains fallowed for over a year, cultivated floodplains within 5 m and 50 m away from the river banks. Each treatment was replicated three times (3 blocks), and samples collected were analysed for K, Na, available P, total N, exchangeable acidity, pH, organic matter, moisture content, sand, silt, and clay. The soil sampling results were subjected to statistical Analysis of Variance (ANOVA) using Randomised Complete Block Design (RCBD), and the difference between treatment means were dictated using F-, student's t and F-LSD/pairwise comparison tests. There was statistically no significant ($p > 0.05$) difference among different floodplains and uplands studied. Upland soils posted 71.67% for the highest pH and 0.09%, 0.87%, 9.74 ppm, 2.23 ppm and 7.264% for the lowest available N, organic matter, Phosphorous, Sodium and Moisture Content, respectively. Cultivated floodplain soil posted highest total P at 29.16 ppm and pH at 6.39% while fallowed floodplains lowest pH at 5.34%, highest available N at 0.32%, highest organic matter at 4.02%, highest K at 21.33%, highest Na at 13.93%, highest exchangeable acidity at 2.32 Cmol/Kg, highest clay content at 14.33%, lowest sand composition at 38.00%, highest silt composition at 54.8% and highest Moisture Content of 32.472%. As depicted by soil fertility analysis results, Manafwa River floodplain and adjacent soils have the capacity to accommodate and boost crop production and productivity. Any nutrients lost to leaching could be gained from subsequent fallowing and sustainable soil fertility management, proper drainage, crop rotation, adding organic manure, and cover cropping, among others.

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INTRODUCTION

A flood is defined as an overflow of excess water arising from accumulated surface run-off on flat lands due to inadequate natural or artificial drains (Vargas, 2017; Njoku et al., 2015; Ibrahim et al., 2016; Ehiorobo & Uso, 2014; Sadiq et al., 2019; Ibeje, 2020). Similarly, a flood is a large amount of water generated from a particular source (such as a river, pond, snow melting glaciers, broken dam, or pipe) towards a previously dried and unsubmerged area (Njoku & Okoro, 2015; Ogbodo, 2011). Globally, flooding is arguably the commonest and most damaging natural disaster (Kaur et al., 2020; Malik & Pal, 2021; Guha-Sapir et al., 2004; Ehiorobo & Uso, 2014; Wakuma Abaya et al., 2009; Borga et al., 2011; Ayugi et al., 2020; Bwala & Ojo, 2021; Ogwuche & Abah, 2014; Odunuga & Raji, 2014; Manta & Ahaneku, 2009; Onifade et al., 2014; Malik & Pal, 2021; Guha-Sapir et al., 2004; Masood & Takeuchi, 2012).

The need to increase agricultural production as a result of increasing population pressure on land resources, competitive land use and declining agricultural productivity of upland soils has brought about increased utilisation of the floodplains to meet man's needs for food and fibre (Orimoloye et al., 2018; Duaibe, 2008). Since most productive agricultural land occurs in low-lying areas along the river, losses to agriculture in extreme flooding are significant (Châu, 2014).

Land use changes associated with development affect flooding in an area in numerous ways; clearing vegetation, removing topsoil, grading or levelling land surface, road or bridge construction and building houses, all of which increase run-off to streams from the rainfall, hence increasing discharge, volume and frequency of floods (Ogbodo, 2011; Duaibe, 2008). Although an increase in flood events in Manafwa catchment is usually attributed to climate change, the nexus between land use and increased surface water run-off suggests that land use changes may also impact floods in the same catchments (Bingwa, 2013). The Manafwa River catchment has experienced increased flood events in recent years resulting from land use changes; as more people use the land for agriculture and housing, the percentage of less pervious and impervious soil surface area increases (Bingwa, 2013).

Despite its significant environmental damages, flooding keeps ecosystems functional numerously, dumping soil nutrients from water bodies into the mainland, hence enhancing soil fertility and productivity (Njoku & Okoro, 2015). Wetting of the floodplains and meadows by floods releases immediate nutrients that were left over from the last flood and those that result from the rapid decomposition of organic matter that has accumulated during the flood (Njoku et al., 2015; Kaur et al., 2020). Further studies have revealed that soil properties such as total porosity, moisture content, pH and organic carbon were higher after flooding than before, whereas others like bulk density, available P and total N were lower in the soil after flooding than before flooding (Rahman & Ranamukhaarachchi, 2003; Ubuoh, 2016; Njoku & Okoro, 2015). Flooding leads to both increases and decreases in soil nutrient content, with the former occurring by availing nutrients that are lacking in the soil (Ubuoh, 2016; Rodríguez et al., 2016). During flooding, floodwater dissolves and transports soil nutrients from flooding surfaces to adjacent rivers and vice versa through lateral flow (Ubuoh, 2016; Tsheboeng et al., 2014; Rahman & Ranamukhaarachchi, 2003). During flooding, soil becomes highly reduced, resulting in a decrease in pH, which leads to an increase in the mobility of soil nutrients such as P, N, Mg, Ca, Na and K through leaching (Orimoloye et al., 2018; Wright et al., 2001). This is because flooding raises the solubility of mineral nutrients hence leaching and

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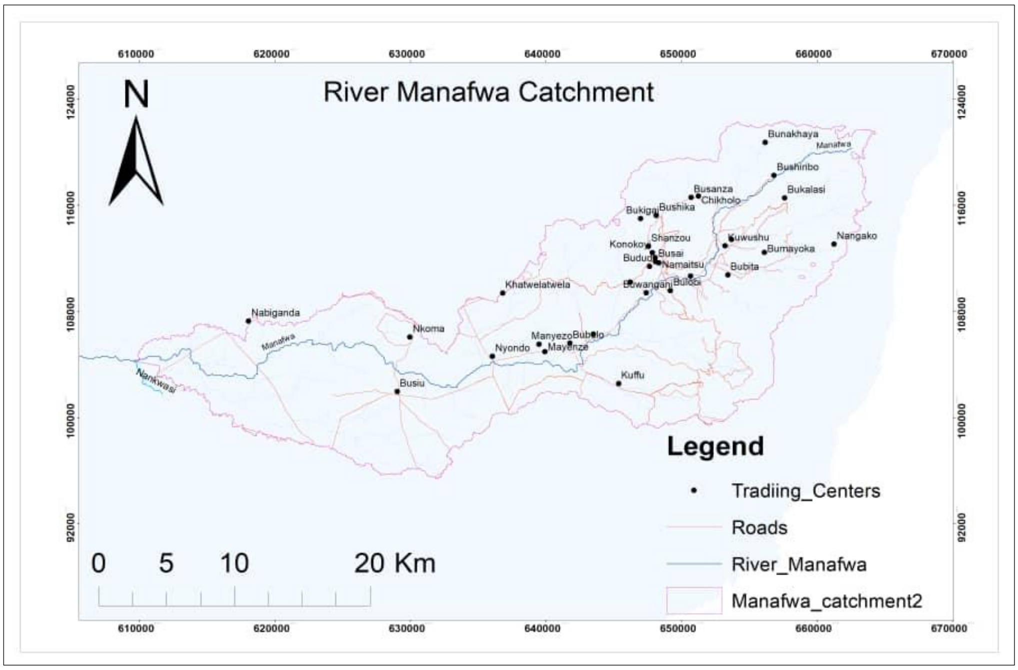
dilution of the macronutrients (Tsheboeng et al., 2014; Rahman & Ranamukhaarachchi, 2003; Ogden et al., 2007). Studies by Eleke et al. (2018), Ogbodo (2011), Ogden et al. (2007) and Gallardo (2003) show that the generally low status of Nitrogen could be due to leaching, volatilisation and other forms of nitrogen losses as a consequence of its high mobility. Therefore, this study aimed to assess the effect of flooding on soil fertility in Manafwa River floodplain soils located in Eastern Uganda.

MATERIALS AND METHODS

Study Area

The study was carried out at Butaleja floodplains on the Butaleja-Kachonga bridge crossing at a coordinate of (0.92829, 33.990378). Manafwa River starts from coordinates of (1.089092, 34.46106) and ends at coordinates of (0.943084, 33.98428).

Figure 1: A map showing the Manafwa catchment area



Source: (ArchGIS, 2022)

Manafwa catchment, just like other parts of Uganda, experiences two distinct rainy seasons (bimodal) a year, crossing the equator; from north to south and from south to north. The first wet season is usually March - May (MAM), with its peak in April, receiving 538 mm of rainfall, whereas the second one in September - November (SON), with peaks in October 418 mm of rainfall (UNMA). Interestingly, both MAM and SON wet seasons coincide with the passage of the Inter Tropical Convergence Zone (ITCZ) that lags behind the overhead sun by about a month, while wet seasons are separated by two dry spells from June to August and December to February (Ogwang et al., 2012). The MAM rainy season is usually more intense (Cecinati, 2013).

Data

The primary data used was obtained from soil sampling of specific sites at Manafwa River floodplains.

Randomised Complete Block Design (RCBD)

In order to minimise experimental variability and maintain uniformity in heterogeneous experimental units, blocking was carried out. Both block and treatment effects were fixed with no interaction. The response for an experimental unit with the i^{th} treatment in the j^{th} block, μ is the overall mean, τ_i is the treatment effect, βj is the block effect and ε_{ij}. The overall sum of block and

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treatment effects was maintained restricted to zero.

The statistical model for RCBD is presented in Equation 1 (Boyle & Montgomery, 1996; Federer & Searle, 1976; Montgomery, 2017; Pilla et al., 2005; Mohammed, 2020).

$$y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \quad (1)$$

where y_{ij} = response of experimental unit with i^{th} treatment in j^{th} block, μ is mean, β_j is i^{th} block and τ_i is j^{th} treatment effects, ε_{ij} = treatment x block interaction or error, *i* = 1, 2,t.

The experimental unit was arranged and classified with the following treatments;

- aau - Unflooding upland characterised by settlements, urbanisation, and agriculture.
- aao - Fallowed floodplain for a year. This is downstream but lying at 100 m from river banks.
- aam - Fallowed floodplain for over a year, lying mid-stream at 200 m from the river banks. Fallowed for over a year meant following for at least 2 years since it is adequate time for the soil to replenish her fertility.
- aan - Cultivated floodplain, located 5 m away from the river bank.
- aad – Cultivated floodplain, located 50 m away from the river bank.

Each treatment was randomly assigned only once in each block. Three (3) replications or blocks 1, 2 and 3 were used, with each block located 100 m apart as per the floodplain site.

Sources of Variations in RCBD

There is variation because some experimental units received different treatments (aau, aao, aam, aan, and aad) - between treatments. There is variation due to the difference between the characteristics of the blocks (1, 2 and 3) - between blocks. There is variation even for experimental units receiving the same treatment - within treatment. From Montgomery (2017), the Analysis of Variance (ANOVA) table is presented in *Table 1*.

Table 1: Analysis of Variance (ANOVA) table for RCBD

Source of variation	Degree of freedom, df	Sum of Squares, SS	Mean sum of squares	F_{stat}
Between treatments, t	(t-1)	SS_{trt}	$MST=SS_{trt} / (t-1)$	
Between blocks, r	(r-1)	SS_{blk}	$MSB = SS_{blk} / (r-1)$	
Within Treatment	(r-1)(t-1)	SS_{Res}	$MSE= SSE / (r-1)(t-1)$	
Total	(rt-1)	SS_{Tot}		

Where t- treatment, r- block/ replication, SS_{trt} - Treatment Sum of Squares, SS_{blk} -Blocking Sum of Squares, SS_{Res} – Error/Residual Sum of squares, MST - Mean Sum of squares Treatment, MSE- Mean Sum of Squares Error; Experimental units were classified into blocks of plots that were as nearly alike as possible; Each treatment occurred in each block the same number of times (usually once).

Statistical Procedure for Analysis of RCBD (after Grant, 2010)

- Construct a two-way table of the totals and means for each block and each treatment level
- Compute the entries in an ANOVA table
- Compute a Coefficient of Variation
- Conduct significance tests.
- Compute means and standard errors.

According to Ambrosius (2007), in a study to produce a statistically significant difference, researchers ought to avail limitations to findings and with completeness of data degree. One that finds no statistical significance calls for investigators to justify the lack of difference was found that sometimes could be due to using

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inappropriate dosage, a too-small sample size, too many dropouts, lack of adherence, or inadequate outcome measurement.

Statistical Computation of ANOVA Entries

From Montgomery (2017), computations of various ANOVA entries are described by equations;

i. Treatment means

$$Treatment\ mean, \bar{y} = \frac{\sum_{j=1}^{r} y_{ij}}{r} \quad (2)$$

ii. Correction factor

$$\frac{G^2}{n} \quad (3)$$

iii. Total Sum of Squares

$$SS_{Tot} = \frac{1}{b}\sum_{ij} y_{ij}^{2} - \frac{G^2}{n}; \quad (4)$$

iv. Total Blocking Sum of Squares (Between blocks)

$$SSB = \frac{1}{t}\sum_{j} T_j^{2} - \frac{G^2}{n}; \quad (5)$$

v. Total Treatment Sum of Squares

$$SST = \frac{1}{b}\sum_{j} T_i^{2} - \frac{G^2}{n}; \quad (6)$$

vi. Residual or Error Sum of Squares

$$SSR/SSE = SS_{Tot} - SS_{Trt} - SS_{blk} \quad (7)$$

vii. Mean Sum of Squares for Error or Residual (MSE)

$$MSE = \frac{SSE}{(t-1)(r-1)} \quad (8)$$

Where t- treatments, r-replications/blocks

viii. Mean Sum of Squares Blocking

$$MSB = \frac{SS_{blk}}{(r-1)} \quad (9)$$

ix. Mean Sum of Squares Treatment

$$MS_{trt} = \frac{SS_{trt}}{(t-1)} \quad (10)$$

x. Variance ratio (F-statistics)

$$F_{stat} = \frac{MS_{trt}}{MSE} \quad (11)$$

If $F_{stat} > F_{tables}$, reject the null hypothesis, there is a significant difference between the treatments.

xi. Standard error of a treatment mean

$$SE_1 = \sqrt{\frac{MSE}{r}} \quad (12)$$

xii. Standard error of the difference between two treatments

$$SE_{1\&2} = \sqrt{MSE}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad (13)$$

Where: G-Grand total, y-treatments, r-replications/blocks

xiii. Two-Sample Student's t-Test

$$t_0 = \frac{(\bar{y}_1 - \bar{y}_2)}{\sqrt{MSE}\left(\frac{1}{r_1} + \frac{1}{r_2}\right)} \quad (14)$$

Where $\bar{y}_2$ treatment means

xiv. Null hypothesis

$$H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4 \quad (15)$$

The null hypothesis of equal means is rejected for treatments 1 and 2 if $\left|\bar{y}_1 - \bar{y}_2\right| \geq LSD_\alpha$

xv. Least Significant Difference, LSD

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$$LSD = t_{(\frac{\alpha}{2},\upsilon)} * \sqrt{MSE}(\frac{1}{r_1} + \frac{1}{r_2}) \quad (16)$$

Where $t_{(\frac{\alpha}{2},\upsilon)}$ is the tabular student's t-test value, α is the significance level and υ is the degree of freedom.

Any treatment means pair that differ in absolute value by more than LSD would imply that the treatment pair is significantly different (Carmer & Walker, 1985). The LSD is the most rightful statistical procedure when appropriately contrasting among treatments, each involving only two of the treatment means (Carmer & Walker, 1985). LSD is only applied once the F-test proves to be significant because the F-test is an approximation to a randomisation test.

Soil Sampling

Soil samples (both auger and undisturbed core) were collected from different sections of blocks 1, 2 and 3. Fallowed and cultivated floodplain soils were selected and randomly sampled using a zigzag pattern at a depth of 0 - 20 cm, which was deemed to be the region where topsoil nutrients lie at the Manafwa River floodplains at Butaleja-Kachonga road bridge crossing. Another sample was picked from the unflooding upland upstream at the same depth to act as the control.

The collected soil samples picked from the different locations were separately crushed using a mortar and pestle, stirred well, and kept in air-tight bags for laboratory analysis.

Laboratory Experiments for Soil Physical and Chemical Properties

Core samples were used to determine soil physical properties (moisture content). The fresh, undisturbed core soil samples were weighed, oven-dried for 24 hrs in the laboratory at 110^0 C and weighed again to determine the gravimetric moisture.

The auger soil samples were weighed, air-dried for 24 - 48 hrs, weighed again, sieved with 2 mm sieve, and stored in polythene bags, and they were used to determine soil chemical properties. Sieved samples with less than 2 mm soil fraction were bagged for particle size distribution analysis (sand, silt, and clay) using the hydrometer method with NaOH as the dispersant. Fresh soil sample was weighed (FW) and oven dried at 105 °C for 24 hrs and re-weighed (DW) to determine the particle density of the materials. Soil pH was determined in distilled water using a glass electrode pH meter and a soil: distilled water ratio of 1: 2.5. Total Nitrogen was determined using the modified Kjeldahl method procedure. Organic carbon was measured by Nelson and Sommers (1982) or combustion at 840 °C (wet-oxidation method) or the Walkey-Black method. Available Phosphorus was obtained using the Melch method. Exchangeable bases (Potassium and Sodium) were determined using flame photometry.

RESULTS AND DISCUSSION

Physical properties results and discussions

As shown in *Table 2* of physical properties, the upland had the highest values of sand at 71.67% compared to the lowest at 38.00% for the fallowed for a year floodplain. The result of particle size distribution clay shows no significant differences among the treatment samples at 95% CI (p>0.05). The fallowed for many years floodplain is highest at 14.33%, followed by the fallowed for a year floodplain at 9.5%. The cultivated floodplain 50 m away from the river banks is lowest at 3.33%. Similarly, for silt, fallowed for one-year floodplain had the highest posting at 52.5%, followed by the cultivated floodplain 5 m next to the river bank at 48.17%. The fallowed for many years floodplains posted the lowest silt, 21.33%. Cultivated floodplains have more silt composition than upland and midstream areas. This is in agreement with Ubuoh (2016), during the studies on the effect of flooding on soil quality in Abakaliki-Nigeria, which concluded that such results are a clear sign of more soil fertility that favours crop production. Soils in floodplains have a higher composition of clay than sand and silt, making floodplains more fertile and favourable for crop production (Ogbodo, 2011)

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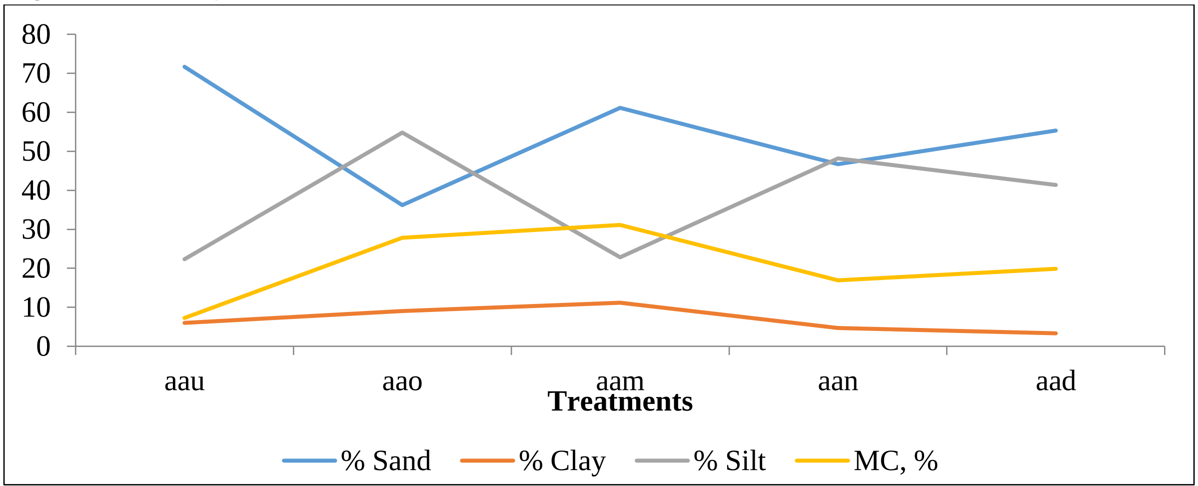
Table 2 Physical properties of the soil samples

Treatment	% Sand	% Clay	% Silt	MC, %	Textural class
aau	71.67	6.00	22.33	7.264	sandy loam
aao	38.00	9.50	52.50	32.472	Loam
aam	61.17	14.33	21.33	31.113	sandy loam
aan	47.167	4.67	48.17	16.913	Loam
aad	55.33	3.33	41.33	19.849	sandy loam
Average	54.67	7.57	37.13	21.52	sandy loam
Means difference, MD	33.667	3.50	30.17	25.21	
F-$LSD_{0.05} = t_{0.025,8}$ * MSE	14.97	7.73	17.809	15.038	
Comparison; MD vs. $LSD_{0.05}$	> LSD	< LSD	> LSD	> LSD	
Inference	S	NS	S	S	

Key;
aau - Unflooding upland characterised by settlements, urbanisation, and agricultural activities.
aao - Fallowed floodplain for a year. This is downstream but lying at 100 m from the river banks.
aam - Fallowed floodplain for over a year, lying mid-stream at 200 m from the river banks.
aan - Cultivated floodplain, located 5 m away from the river banks.
aad - Cultivated floodplain, located 50 m away from the river banks.

Figure 2: Soil physical properties



The textural class ranged from loam and sandy loam in the flooding lowlands near/along the river to sandy loam in the uplands. The highest moisture retention was observed at 32.47% for fallowed for one-year floodplains, followed by fallowed for over one-year floodplain at 31.13%. The upland had the lowest moisture content at 7.264%. According to Njoku et al. (2011) and Kozlowski (1997), high moisture content in the flooding lowlands could be because the soil pores in flooding lowlands are usually filled with water against air that fills mainly upland soil pores. Similarly, the highest moisture content satisfies findings by Njoku & Okoro (2015), who observed that the high moisture content in the flood meadows, as compared to control, may be a result of materials such as debris, silt and microscopic organisms that are usually brought to the flood meadow by flood that help to improve properties of flood meadow soil.

Chemical Properties Results and Discussion

From *Table 3* of Chemical properties, there is an indirect proportionality between pH and organic matter. The pH posting was highest for cultivated floodplains 50 m away from the river banks at 6.39, while the annual fallowed flooding lowlands had the lowest value at 5.34. Similarly, the organic matter postings were lowest at 0.87% in the upland and highest at 4.02% in the floodplains, fallowed for one year. The average pH value for all treatments is 6.00, which is slightly acidic. The high pH and low organic matter values registered in the uplands are due to low exchangeable acidity

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and high exchangeable bases of Ca^{2+} and Mg^{2+} that naturally displaced H^+ from the exchange complex into the soil solution, hence leaching (Ogbodo, 2011). A study by Rahman & Ranamukhaarachchi (2003) to investigate the fertility status and environmental consequences of Tista floodplain soils in Bangladesh revealed that the acidic nature of floodplain soils could be due to the organic matter decomposition and release of H^+ by Al^{3+}. Similarly, according to Udo et al. (2009), the moderately acidic pH value is an indication that a significant amount of exchangeable H^+ by Al^{3+} is present to affect plant growth. The pH treatment means the difference is 0.71, which is less than the F-$LSD_{0.05}$ value of 0.782 for pH at α = 0.05 level of significance. According to Montgomery (2017), this result implies that there is no significant difference between the upland and the floodplains fallowed for a year for pH.

Table 3: Selected Chemical properties of the soil samples

Treatment	pH, H_2O	N, %	OM, %	P, ppm	K, ppm	Na, ppm	Exchangeable acidity, mol/Kg
aau	6.05	0.09	0.87	9.74	10.35	2.23	0.93
aao	5.34	0.32	4.02	19.17	16.45	13.93	2.32
aam	5.96	0.20	3.13	21.87	21.33	13.93	1.28
aan	6.25	0.17	1.58	25.49	10.95	9.05	0.75
aad	6.39	0.13	1.06	29.16	9.57	9.37	1.40
Means difference, MD	0.71	-0.23	-3.93	-9.43	-6.10	-11.7	-2.23
F-$LSD_{0.05}$ = $t_{0.025,8}$ * MSE	0.782	0.172	2.246	12.52	8.119	3.349	2.524
Comparison; MD vs. $LSD_{0.05}$	< LSD	> LSD	> LSD	< LSD	< LSD	> LSD	< LSD
Inference	NS	S	S	NS	NS	S	NS

Key; < - Less than; NS – Non-significant; Fp – Flood plains

For Nitrogen, the absolute treatment means the difference is 0.23% which is greater than F-$LSD_{0.05}$ value of 0.172% at α = 0.05 significance level. According to Montgomery (2017), this result implies that there is a significant difference between the upland and the floodplains fallowed for over a year for Nitrogen. This result supports findings by Ubuoh (2016), during the study of the effects of flooding on soil quality in Abakaliki agro-ecological zone, Nigeria that concluded that there were significant differences among treatments in total Nitrogen, a strong indication of rapid fruiting and ripening of fruits. Flooding lowlands fallowed for a year posted the highest percentage at 0.32%, followed by the floodplains fallowed for over a year at 0.20% as compared to the lowest posting of 0.09% from the upland. The higher nitrogen content in the floodplains and lower posting in the uplands is because of volatilisation of Nitrogen and plant uptake of available N in the uplands (Eleke et al., 2018). Studies by Eleke et al. (2018), Ogbodo (2011), Ogden et al. (2007) and Gallardo (2003), the generally low status of Nitrogen could be due to leaching, volatilisation and other forms of nitrogen losses as a consequence of its high mobility.

Similarly, the Organic Matter, OM treatment means the difference is 3.93% which is greater than the F-$LSD_{0.05}$ value of 2.246% for OM at α = 0.05 level of significance. According to Montgomery (2017), this result implies that there is a significant difference between the upland and the floodplains fallowed for over a year for OM. This result supports findings by Ubuoh (2016), during the study of the effects of flooding on soil quality in the Abakaliki agro-ecological zone of the south-eastern state, Nigeria that concluded that there was a significant difference among treatments in per cent organic matter since the control (upland) had the most of the organic matter decomposed into humus.

Flooding lowlands fallowed for a year posted the highest value at 4.02%, followed by the fallowed for over a year floodplain with 3.13% as compared

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to the least value of 0.87% from uplands. The average OM registered for all treatments was 2.13%, and the sampling areas bordering the river banks (near the river banks and away from the river) with frequent crop cultivation every season posted very low OM contents of 1.58 % and 1.06 %, respectively. The upland area and the frequently cultivated land – 50 m away from the river banks have significantly lower OM (Organic Matter) content than the fallowed (one year fallowed and over a year fallowed) at 0.87% and 1.06 %, respectively. The high organic matter content in the fallowed floodplains is due to the accumulation of residues of the fallow vegetation over time and the additional biomass deposits brought by flood water. This statement is supported by the findings of Afu et al. (2019), who analyzed the agricultural potential of floodplain soils in Cross River State, Nigeria. The low organic matter content in the frequently cultivated lands is due to the constant crop uptake during growth. This supports the findings by Njoku et al. (2011), who he concluded that the low organic matter and nitrogen content in the upland could be due to the more frequent cultivation of seasonal crops as compared to the flooding lowlands that are seldom cultivated in fear of flooding. Also, according to Njoku & Okoro (2015), the improved soil properties around the fallowing area as compared to the upland may be attributed to the presence of vegetation, which regained back the leached nutrients through root absorption and decomposition of plant residues. Similarly, wetting of the flood meadows releases immediate nutrients that were left over from the last flood and those resulting from accumulated decomposed organic matter from floods (Njoku et al., 2015). Similarly, studies by Iwegbue et al. (2020b) found that a decrease in Polycyclic Aromatic Hydrocarbons (PAH) concentrations in cultivated floodplains one year after floods had receded were associated with volatilisation of PAHs, absorption, leaching, biological degradation and land farming. Similarly, regarding the decrease in organic matter content in upland and cultivated flood plains, Iwegbue et al. (2020b) concluded that flood-sediment regulation has a negative impact on temporal changes in soil organic carbon (SOC) content of floodplain soils. Multiple drying and wetting cycles dominated by overbank low from flood sediment regulation would enhance the decomposition of SOC.

Also, periodic changes in aeration or water tables affect cumulative carbon mineralisation rates in laboratory columns of peat land soils. In addition, changes in soil salinity due to freshwater inputs could stimulate soil organic matter loss since soil salinity has strong correlations with microbial biomass and soil organic matter content (Iwegbue et al., 2020b). A study by Ogbodo (2011) to evaluate and compare the fertility status of Abakaliki-Nigeria flood plains soils with upland attributed the higher values of organic matter in the floodplains and river basins to long-term accumulation of residues and deposits resulting from floods. Upland cultivation led to organic decomposition and reduced organic materials to run-off or erosion (Ogbodo, 2011). The low to moderate OM levels above are also in line with Negash & Mohammed (2014) findings during the study to determine the soil fertility of Koka Nagawo - Oromia - Ethiopia. It attributed the low OM levels in the upland to high temperatures that raise the organic matter decomposition rate alongside continuous crop cultivation with complete removal of crop residue, limited application of farmyard manure and zero crop rotation. The high organic matter content in fallowed floodplains leads to the poor drainage of the soil and the periodic inundation from flooding which greatly lowers the rate of organic matter decomposition (Negash & Mohammed, 2014).

Similarly, for Phosphorus (P), the cultivated lowlands about 50 m away from the River Manafwa banks posted the highest value of 29.16 ppm as compared to the upland areas that posted the lowest Phosphorus value of 9.74 ppm. A similar study by Wright et al. (2001), to examine the effects of flooding on P availability in a forested floodplain eco-system in Georgia, USA, revealed an increase in Phosphorus availability in response to artificial flooding as compared to control. Conclusively, the increase in phosphorus availability in the floodplains in Georgia was due

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to Phosphorus solubilisation from Phosphorus minerals.

This could have been a similar case for P increase in Butaleja floodplains. Previous research has also attributed P increase in floodplains to geochemical sources, i.e. reduction and dissolution of Iron (Fe III) phosphates and dissolution of Fe and Aluminum (Al) phosphates or the release of clay-associated phosphates through anionic exchange (Wright et al., 2001).

Another explanation for the increase in P is due to P inputs from the upstream crop fields, a decrease in biological P demands resulting from anaerobic conditions that cause dormancy of aerobic plants or micro-organisms and the release of labile P from microbial biomass (Wright et al., 2001). A study by Rahman & Ranamukhaarachchi (2003) to investigate fertility status and environmental consequences of Tista floodplain soils in Bangladesh concluded that the higher P content in flooding and cultivated floodplains is due to the excess P transported by surface run-off from the upstream croplands.

For exchangeable bases (K, Na), the fallowed floodplains for more years presented the highest values for K and Na, with 21.33 ppm and 13.93 ppm, respectively. These were followed by floodplains fallowed for one year with 16.45 ppm and 9.37 ppm, respectively. However, the upland areas presented the lowest value of Na at 2.23 ppm, whereas cultivated land 50 m away from the river banks presented the lowest K values at 9.57, followed by the upland area at 10.35 ppm. The Na content of the cultivated floodplains – 5 m from the river bank and along the river were insignificantly the same at 9.05 and 9.37 ppm, respectively. The significantly higher exchangeable bases of K and P in the fallowed floodplains than in the uplands satisfy the findings of Ogbodo (2011) and Nsor & Akamigbo (2009), who concluded that these elements could have been eroded from uplands and deposited on the floodplains. The significantly low exchangeable bases in the uplands are due to nutrient mining by the crops. The soil Na content was significantly higher on the fallowed floodplains. Ogbodo (2011) concluded that this is because flood water carries along salts that are eventually deposited on the floodplain soils. As the water recedes, evaporation occurs, leaving salts, crusts and crystals, hence the high Na content in the fallowed area. The slightly lower Na content in the cultivated flood plains is due to the nutrient uptake of Na during plant growth.

For Potassium (K), the treatment means the difference is 6.10 ppm which is less than the F-$LSD_{0.05}$ value of 8.119 ppm for K at $\alpha = 0.05$ level of significance. According to Montgomery (2017), this result implies that there is no significant difference between the upland and the floodplains fallowed for over a year for K. For Sodium (Na), the treatment means the difference is 11.7 ppm which is greater than the F-$LSD_{0.05}$ value of 3.35 ppm for Na at $\alpha = 0.05$ level of significance. According to Montgomery (2017), this result implies that there is a significant difference between the upland and the floodplains fallowed for over a year for Na. This result supports findings by Ubuoh (2016) during the study of the effects of flooding on soil quality in Abakaliki agro-ecological zone of the south-eastern state of Nigeria. The study concluded that there was a significant difference between treatments at $p < 0.05$ for Na, an indication of possible loss in exchangeable cations during flooding, possibly as a result of leaching.

Similarly, for exchangeable acidity, the treatment means the difference is -2.23, which is less than the F-$LSD_{0.05}$ value of 2.524 at $\alpha = 0.05$ level of significance. According to Montgomery (2017), this result implies that there is no significant difference between the upland and the floodplains fallowed for over a year for exchangeable acidity. Exchangeable acidity is highest in a year fallowed floodplains at 2.32 Cmol/Kg, whereas the lowest values are presented by cultivated floodplains – 5 m from the river banks at 0.75 Cmol/Kg. This is followed by an upland area that has an exchangeable acidity of 0.93 Cmol/Kg. High exchangeable acidity results positively correlate with a study by Orimoloye et al. (2018) to characterise and classify floodplain soils in

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Nigeria. This is because of high Aluminum (Al) saturation arising from dominant Al^{3+} exchangeable Cation in soils that causes Aluminum toxicity.

CONCLUSION AND RECOMMENDATIONS

This study aimed to assess the impacts of floods on soil fertility of the Butaleja River Manafwa floodplain soils. From the analysis of the Manafwa floodplain properties, sand, moisture content, silt, sodium, Nitrogen, and organic matter present statistically significant relationships between the control treatment (uplands) and floodplains fallowed for one year, floodplains fallowed for over a year and cultivated river banks when subjected to F-test, students' t-test, and F-LSD/ pairwise comparison tests. However, there are no statistically significant relationships for Nitrogen, Phosphorus, clay, pH, organic matter, sodium, and exchangeable acidity between the control treatment (uplands) and floodplains fallowed for one year, floodplains fallowed for over a year and cultivated river banks when subjected to F-test, students' t-test, and F-LSD/ pairwise comparison tests. Potassium presented a mixed signal of results and was treated as an outlier. Although the F-test produces a statistically significant value for Potassium, the t-test, F-LSD, and Chi-square test produces non-significant test results for the same.

From the results of soil physical and chemical properties, numerous characteristics suitable for crop production, including pH, soil N, OM, available P, soil moisture, exchangeable bases and textural composition, were studied. From the chemical analysis, it is apparent that Manafwa River floodplain soils in Butaleja are lightly acidic, average in organic matter content, low in total N, and high in available P and exchangeable bases. The floodplain soils present higher organic matter content that reflects higher productivity and reduced decomposition and mineralisation rates. The floodplain soils also tend to be more fertile than adjoining upland areas, and the availability of moisture makes them even more suitable for year-round cropping. The productive nutrient status of the Butaleja floodplain soils makes them able to sustain agricultural productivity.

From the results of statistical analysis, it can be seen that more research is required to determine the behaviour of the Chi-square test, F-LSD/pairwise comparison and t-test even when the F-test says no significant difference between treatments. Particularly the behaviour of Potassium since it shows a mixture of contradicting signals with the F-test that produces a statistically significant value and the t-test, F-LSD and Chi-square test that yield non-significant test results.

However, soil fertility restoration and production enhancement measures to contain soil acidity and boost organic manures should be adopted for more sustainable crop production. These may include the application of farm yard manure/organic manure, practising crop rotation, growing leguminous crops, cover crops, intercropping, and mulching. Other sustainable land management practices include proper drainage, dry season irrigation, intercropping, fallowing, among others, can be applied to sustainably grow more crops in the long run while avoiding acid-forming inorganic fertilisers to avoid further leaching and compounded acidity. The inhabitants continue to grow high-value crops (fruits and vegetables) in the uplands, and rice, yams, and other water-logging crops have been reserved for the flooding floodplains/lowlands near or along the river.

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