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Analysis of Monthly Micronutrient Loss in Fallows of Different Ages in Southern Nigeria

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Abstract

The study examined monthly loss of micronutrient in 10-year old, 5-year old and 3-year old fallows and abandoned farmland in a part of the rainforest zone in southern Nigeria. Measurements of 54 rainfall producing sediment were carried out from March to November in 2012 rainy season. The results indicated that the months of July, August and September recorded high micronutrient losses with July experiencing the highest micronutrients losses followed by August. High micronutrient losses on the 10-year old fallow plot occurred in August; July on the 5-year, 3-year fallow and abandoned farmland. The amount of micronutrient losses varied significantly among the plots ($p<0.05$). The 5-year old fallow experienced the highest nutrient losses, followed by the abandoned farmland, while the 10-year fallow experienced the lowest losses. High micronutrient on the 5-year old fallow was attributed to previous land use history of unintended bush fire which resulted in the burning of herbaceous species. The result showed that substantial quantity of micronutrient loss occurred on fallows with decreasing vegetal and herbaceous cover.

Keywords: Fallow vegetation, Micronutrient loss, Monthly losses, Agoi-Ekpo

1. Introduction

In the tropics, rainfall frequency and intensity have severe impacts on soil erosion which affects soil quality and plant health in agricultural systems (Dourte et al., 2015). Rainfall frequency and intensity result in soil erosion which usually results in the removal of large quantities of nutrients from the soil in both dissolved and sediment-bound forms (Frerer and Gabet, 2002; Iwara et al., 2017). In tropical Africa, soil erosion is a serious environmental problem which usually depletes the soil of essential nutrients making it impoverished for agricultural production. One of the sediment-bound form nutrients loss from the soil by soil erosion is micronutrients. Micronutrients are required by plants though in minute quantities. Micronutrients such as zinc (Zn), iron (Fe), copper (Cu), manganese (Mn) and other trace elements are essential for plant growth in very small quantities. Micronutrients have agronomic importance in the soil and as such, they play vital roles in the growth and development of plants; this makes them are essential for plant growth (Nazif et al., 2006; Mustapha et al., 2011).

The loss however of these nutrients could have inherent effect on plant health and productivity. For instance, Zn is known to promote the formation of growth hormones, starch and seed development; Cu is involved in photosynthesis; Fe is important in chlorophyll formation, while Mn is known to activate a number of important enzymes and is important in photosynthesis and metabolic processes (Oku et al., 2012). The amount of essential topsoil micronutrients loss in sediment can vary at different temporal scales. This makes it necessary to monitor the time-period of such losses in order to understand or identify the month with the highest losses. Such knowledge will enable appropriate land management measure to be put in place. In line with this, Dourte et al., (2015) stated that in agriculture, the movement of nutrients is impacted by the timing and intensity of rainfall (Dourte et al., 2015).

Increased rainfall frequencies, amount and intensities may lead to increased soil loss, and if unchecked can affect soil quality and agricultural productivity. Thus, the overall productivity and potential of the soil to support agricultural production is affected as a result of the depletion of nutrient resources (Pimentel and Kounang, 1998). They further argued that if soil conservative measures are not put in place, maximum nutrient input in a fallow farmland may be interrupted and delayed. With the increasing human population and shortening in fallow period, a piece of land may not have the required nutrient base to enhance crop yield as a result of the constant loss of nutrient elements. This affects land productivity due to the loss of essential nutrients. In Nigeria and many other countries of the world, farmlands are usually allowed to fallow after a period of food crop cultivation. The essence is to enable the soil regains its lost nutrients after a period of disturbance. However, during the period of vegetation regrowth, the soil having lost its vegetal cover to farming activities is exposed to soil erosion process which result in the loss of micronutrient in liquid and sediment bound forms. The loss of nutrient can be high on fallow land with less cover (canopy and herbaceous cover). The change in vegetation makes the soil susceptible to soil erosion. Soil erosion intensity and erosional losses (runoff and sediment) differ from one location to the other and from one month to the other as a result of the differences in vegetation characteristics, differences in topography and soil types, differences in rainfall intensity and volumes among others (Daura, 1995).

The seasonality of rainfall and its adequate timing by farmers enables proper planning to be carried out to reduce the loss of essential nutrients. Identifying the periods or months with increased nutrient loss will enable proper soil management practices to be put in place by farmers and land managers to reduce the quantities of essential topsoil nutrient loss. Literature on micronutrient loss mostly at temporal scales in fallows of varying ages is not readily available in the literature. Available studies in the literature placed more emphasis on macronutrient losses on different land uses such fallows, clear-cutting and burning area, vegetation patches, cropping system and plantations (Adedeji, 1984; Daura, 1995; Ries and Langer, 2001; Vásquez-Méndez et al., 2010; Kizza et al., 2013) are available on nutrient loss in fallows of different ages. These studies did not show monthly account of micronutrient loss and identify months of high nutrient loss in fallows of different ages. This paper therefore contributes an understanding in this regard by examining the temporal variation (monthly) in micronutrient loss in fallows of different ages in southern Nigeria. The present study assessed the rate of micronutrient loss in fallows of 10-year, 5-year, 3-year and abandoned farmland.

2. Material and Methods

2.1. Study Area

The study was carried out in Agoi-Ekpo, one of the villages in Yakurr Local Government Area of Cross River State. Its geographical coordinates are 5° 50' 0" North and 8° 16' 0" East. The area falls within the lowland of south-eastern Nigeria called the Cross River plain. The relief is gentle except in places where granite rises above the general level of the surface (Iloeje, 2009; Iwara, 2013). Agoi-Ekpo lies within the hot-wet equatorial climate of the tropics characterized by high temperature, heavy rainfall and high relative humidity. Vertisol are the main soils type found in the area. The geology/parent material is of cretaceous sediments (Oden et al., 2012). The area has luxuriant forest vegetation.

2.2. Site sampling and Installation of Runoff Plots

Fallows of 10-years, 5-year, 3-years and abandoned farmland were identified and used to estimate nutrient loss. In each identified fallow community, a plot of 10m x 4m was constructed from which sediment loss was obtained. All plots were 10m long and 4m wide giving a total area of 40 sq. meters (0.004 hectare). At the tail end of each plot, a gutter for runoff collection was constructed at the outlet and storage container (i.e. a 250-litre container drum) was installed to collect runoff after each rainstorm. The collection container was installed in a pit of 5m by 5m wide and 3.5m deep. The PVC pipe performed the function of conveying the runoff and sediment into the collection container. The sediment that settled at the bottom of the container was obtained by adding some amount of the runoff water, rigorously stirred and collected in the plastic bucket. After which, the sediment was emptied into polythene bags with labels.

2.3. Laboratory Analysis and Estimation of Nutrient Loss

The sediment was air dried sediment and taken to the laboratory for analysis of iron (Fe), copper (Cu), manganese (Mn), zinc (Zn) and lead (Pb). The micronutrients were extracted using 0.1 m HCl solution (Osiname et al., 1973) and determined using an atomic absorption spectrometer. Micronutrient loss in kilogramme per hectare (kg ha^{-1}) was estimated following the formula given by Ali et al., (2007) and Munodawafa (2012) as follows.

$$\text{Nutrient Loss}\left(\text{kg ha}^{-1}\right) = \frac{\text{Nutrient concentration}\left(\text{mg/kg}\right)\text{ x Sediment loss}\left(\text{kg ha}^{-1}\right)}{1000\,000}$$

2.4. Data Analysis

Data collected from the field were statistically treated using Tables, Averages and One-Way Analysis of Variance (ANOVA).

3. Results

3.1. Micronutrient Element Losses on the Fallow Plots

During water erosion, soil nutrient is eroded either in sediment or dissolved in runoff. For this study, measurement of nutrient loss was restricted to eroded sediment. Studies (Wang and Liu, 1999; Wang et al. 2005) indicate that the main model of soil nutrient loss is related to sediment loss. Micronutrient element losses from eroded sediment in the respective plots are summarized in Table 1. Manganese (Mn) loss was high on 5-year old fallow plot and low on 10-year old fallow plot with mean values of 4.19 g ha^{-1} and 0.25 g ha^{-1} respectively. The loss in total Mn varied significantly among the fallow plots ($F = 5.872$, $p<0.05$). This result indicates that Mn loss in the soil is minimized through the availability of surface cover. Similar trend in micronutrient loss was obtained for iron (Fe), copper (Cu) and zinc (Zn). The low losses in Fe, Cu and Zn on the 10-year old and 3-year old fallow are indicative of the importance of vegetation mostly ground and crown cover in minimizing the rate of nutrient loss. Total Fe, Cu and Zn loss varied significantly among the plots ($p<0.05$).

Table 1: Micronutrient loss on abandoned farmland and fallow plots

Nutrients	Plots	N	Sum	Mean	Std. Error	F-ratio
Mn (g/ha)	10-year old	54	13.50	0.25	0.12	5.872*
	5-year old	54	226.20	4.19	1.30	
	3-year old	54	46.90	0.87	0.28	
	Abandoned farmland	**54**	**144.20**	**2.67**	**0.64**	
Fe (g/ha)	10-year old	54	1.50	0.03	0.01	4.890*
	5-year old	54	41.40	0.77	0.26	
	3-year old	54	7.30	0.14	0.04	
	Abandoned farmland	54	24.80	0.46	0.15	
Cu (g/ha)	10-year old	54	0.09	0.002	0.001	5.295*
	5-year old	54	1.54	0.029	0.008	
	3-year old	54	0.28	0.005	0.002	
	Abandoned farmland	54	1.10	0.020	0.007	
Zn (g/ha)	10-year old	54	3.50	0.06	0.03	1.625
	5-year old	54	42.90	0.79	0.49	
	3-year old	54	8.30	0.15	0.08	
	Abandoned farmland	54	22.10	0.41	0.14	

* Significant at 5% confidence level

3.2. Monthly Total Nutrient Losses (kg ha^{-1}) on the Fallow Plots

Micronutrient element losses from the month of March to November are shown in Tables 2 and 3. The result shows that the amount of total micronutrient loss increases with the frequency and total amount of rainfall.

3.3. Micronutrient Losses in March to May

Table 2 shows the amount of micronutrient eroded from the soil from March to May in the fallow plots. March was the month the experiment commenced and it experienced a single rainfall of 12.7 mm that resulted in no loss of micronutrient. In April, there was a significant increase in the quantities of micronutrients eroded from the soil. Seven (7) rainfall events with a cumulative total of 125.6 mm resulted in considerable quantities of micronutrients eroded from all the plots. The abandoned farmland experienced the highest loss of Mn followed by the 5-year old plot with values of 10.20 and 8.80 g ha^{-1} respectively. The information indicates that Mn suffered the highest losses, while Cu suffered the lowest losses in the respective plots. In May, there was also a substantial increase in the quantities of micronutrients eroded in the soil with the frequency of rainfall and amount of rainfall. There was a significant increase in the quantities of Mn, Zn and Fe washed away from the topsoil mostly on the 5-

year old and abandoned farmland plots. Also, seven (7) rainfall events with a cumulative total of 156 mm resulted in large amount of surface micronutrients eroded from the soils (Table 2). The pattern observed showed that Mn, Zn and Fe suffered the highest micronutrient losses on all the plots implying that the eroded soils were enriched in micronutrients.

Table 2: Total monthly micronutrients loss from March to May

Months	Nutrients	Plots			
		10-year	**5-year**	**3-year**	**Farmland**
March	Mn (g ha^{-1})	0.00	0.00	0.00	0.00
	Fe (g ha^{-1})	0.00	0.00	0.00	0.00
	Cu (g ha^{-1})	0.00	0.00	0.00	0.00
	Zn (g ha^{-1})	0.00	0.00	0.00	0.00
	Rainfall amount = 12.7mm; Rainfall frequency = 1				
April	Mn (g ha^{-1})	0.60	8.80	2.50	10.20
	Fe (g ha^{-1})	0.10	1.20	0.10	0.50
	Cu (g ha^{-1})	0.00	0.07	0.02	0.10
	Zn (g ha^{-1})	0.00	0.60	0.30	0.70
	Rainfall amount = 125.6 mm; Rainfall frequency = 7				
May	Mn (g ha^{-1})	1.00	12.30	4.00	21.30
	Fe (g ha^{-1})	0.10	2.70	0.60	1.90
	Cu (g ha^{-1})	0.00	0.11	0.04	0.30
	Zn (g ha^{-1})	0.10	0.70	0.10	5.00
	Rainfall amount = 156 mm; Rainfall frequency = 7				

3.4. Micronutrient Losses in June to August

In June, five (5) rainfall events with a cumulative total of 121.5 mm were recorded resulting in varying quantities of nutrients eroded from the fallow soils (Table 3). Total micronutrient loss in the month of June followed the pattern reported for April and May. High micronutrient losses in June were recorded on the abandoned farmland and 5-year old fallow, while the 10-year old fallow experienced the lowest losses in micronutrient elements. Again, Mn, Fe and Zn experienced the highest losses on all the plots in June, while Cu had the lowest losses. The month of July displayed a distinct pattern in nutrient losses in the respective plots, as high nutrient losses was experienced on the 5-year old fallow plot, followed by the abandoned farmland (Table 3). The rapid growth in herbaceous species had implications on the reduced quantities of micronutrient eroded from the 3-year old fallow. It was the month with the highest frequency of rainfall events (11) and highest rainfall amount (267.4 mm). The losses in Mn, Fe and Zn on the 5-year old fallow showed a considerable increase. Characteristically, Mn, Fe and Zn suffered the highest losses on all the plots. The losses in these nutrients far exceeded the values recorded in April, May and June. This further implies that micronutrient losses from the soil increases with the rains. However, low losses in Mn, Fe and Zn were recorded on the 10-year old and 3-year old fallow plots due to the existence of dense crown cover and ground cover percentage respectively that afforded the soil protection against the direct effect of raindrops.

Table 3: Total micronutrients loss from June to August

Months	Nutrients	Plots			
		10-year	5-year	3-year	Farmland
June	Mn (g ha^{-1})	1.20	10.10	6.10	22.00
	Fe (g ha^{-1})	0.10	2.20	0.60	5.30
	Cu (g ha^{-1})	0.00	0.13	0.02	0.10
	Zn (g ha^{-1})	0.10	0.50	0.70	3.70
	Rainfall amount = 121.5 mm; Rainfall frequency = 5				
July	Mn (g ha^{-1})	1.70	56.30	10.40	30.50
	Fe (g ha^{-1})	0.20	8.00	1.60	3.90
	Cu (g ha^{-1})	0.02	0.40	0.50	0.00
	Zn (g ha^{-1})	0.60	33.00	6.20	9.40
	Rainfall amount = 267.4 mm; Rainfall frequency = 11				
August	Mn (g ha^{-1})	6.10	88.30	13.80	38.80
	Fe (g ha^{-1})	0.50	7.10	1.80	6.40
	Cu (g ha^{-1})	0.05	0.43	0.07	0.40
	Zn (g ha^{-1})	1.50	2.30	0.60	2.80
	Rainfall amount = 236.3mm; Rainfall frequency = 7				

Comparable to the months of April and May, seven (7) rainfall events with a cumulative total of 236.3 mm resulted in substantial quantities of micronutrients eroded from the plots in August. There was a significant increase in the quantities of nutrients eroded from the soils, with high and low nutrient losses experienced on the 5-year old fallow and 10-year old fallow plots respectively. Similar pattern in Mn, Fe and Zn losses recorded in April, May, June and July was also observed on the fallow plots and abandoned farmland plot respectively in August. Mn and Fe suffered the highest micronutrient losses on the 5-year old fallow suffered the highest nutrient element loss, followed by the cultivated farmland, while the lowest loss in surface micronutrient in August was recorded on the 10-year old fallow.

3.5. Micronutrient Losses from September to November

In September, seven (7) rainfall events with a cumulative total of 264.4 mm were recorded across the treatments. High micronutrient loss in the month of September followed the pattern reported for other months. High micronutrient losses in September were recorded on the 5-year old fallow followed by abandoned farmland, while the 10-year old fallow experienced the lowest losses in micronutrient elements. The quantities of topsoil micronutrient lost in September showed that Mn, Fe and Zn experienced the highest losses (Table 4). In comparison with the micronutrient losses recorded in other months, there was a drastic reduction in the quantities of soil micronutrients eroded from the soils in October. This reduction could be attributed to the decrease in rainfall amount. Though, eight (8) rainfall events with a cumulative total of 124.3mm were recorded across the plots (Table 4), the rainstorms were not heavy to greatly enrich sediment the eroded sediment. The rainfall events in this month signaled the gradual end of the rainy season. High micronutrient losses in October were recorded on the 5-year old fallow, while the 10-year old experienced the lowest losses in nutrient elements. The quantities of topsoil micronutrient loss in October showed that Mn and Fe suffered the highest losses, while Cu followed by Zn had lowest losses (Table 4). In November, a single rainstorm with measurable runoff and eroded sediment was recorded. Though, there were sporadic rainstorms, the rainstorms did not generate runoff across the plots as the amounts were >5 mm. The only rainfall event of 10.0 mm did not result in micronutrient losses across the plots (Table 4). This month was the end of the field experiment and the end of the 2012 rainy season in the study area.

Table 4: Total nutrients loss from September to November

Months	Nutrients	Plots			
		10-year	**5-year**	**3-year**	**Farmland**
September	Mn (g ha^{-1})	2.90	49.20	10.00	21.10
	Fe (g ha^{-1})	0.50	20.10	2.60	6.80
	Cu (g ha^{-1})	0.02	0.40	0.08	0.20
	Zn (g ha^{-1})	1.20	5.80	0.40	0.50
	Rainfall amount = 264.4 mm; Rainfall frequency = 7				
October	Mn (g ha^{-1})	0.00	1.20	0.10	0.30
	Fe (g ha^{-1})	0.00	0.10	0.00	0.00
	Cu (g ha^{-1})	0.00	0.00	0.00	0.00
	Zn (g ha^{-1})	0.00	0.00	0.00	0.00
	Rainfall amount = 124.3 mm; Rainfall frequency = 8				
November	Mn (g ha^{-1})	0.00	0.00	0.00	0.00
	Fe (g ha^{-1})	0.00	0.00	0.00	0.00
	Cu (g ha^{-1})	0.00	0.00	0.00	0.00
	Zn (g ha^{-1})	0.00	0.00	0.00	0.00

Rainfall amount = 10.0 mm; Rainfall frequency = 1

4. Discussion of Findings

The results show an apparent temporal variation in the amount micronutrient element losses across the plots. High micronutrient losses were experienced on the abandoned farmland and 5-year old fallow which may be attributed to the similarities in vegetation characteristics (existence of sparse herbaceous cover and low litter depth) mostly at the onset of the experiment. The monthly losses in micronutrient elements show that there is a continuous loss in topsoil micronutrient with the rains and across the months. This is because the quantities of micronutrient lost from the fallow soils depend on the frequency and number of rainstorms recorded monthly. The highest micronutrient losses on the 10-year, 5-year, 3-year and farmland plots occur in August. Micronutrient losses on all the plots increased with rainfall and runoff volume from the months of April to September, thereafter; there was gradual reduction in micronutrient losses on the entire plot with the reduction in rainfall frequency and amount. Particularly, the months of June, July, August and September yielded high losses of total micronutrients on all the plots. Separately, August and September experienced the most loss of micronutrients. This is expected as these months are usually associated with heavy rainstorms and more frequent rainfall events. The monthly analysis in micronutrient element loss indicates an increasing trend in nutrient loss at the onset of the rains on all the treatments. The total micronutrient loss in the later period of the year shows a decreasing trend, as a result of the increase in the density of herbs and herbaceous cover with the rains mostly on the 3-year old fallow and farmland. In the later period of the experiment (precisely July to November), micronutrient losses became high on the 5yr-old fallow than on the abandoned farmland. This is so as the 5yr-old plot was highly susceptible to erosion due to its scanty ground cover potentials and the characteristic of the vegetation cover (canopy gaps). Thus, the canopy gaps and scanty undergrowth (low density of herbs) on the 5-year fallow made the plot susceptible to soil erosion. The increase in the density of herbs on the 3-year fallow and farmland provided adequate cover to the soil, thereby minimizing runoff and associated losses.

In concise, the change in vegetation characteristics was observed to have substantial effects on the amount of micronutrient losses experienced on all the plots, as there was a gradual reduction with the growth in vegetation (herbaceous cover and density of herbs) mostly on the 3-year fallow and farmland. The growth in herbaceous cover and density of herbs on the 5-year fallow was slow, with almost no noticeable difference between the ground cover in March and those in November. Also, it is worthy of note that the scanty ground cover (undergrowth) and litter depth noticed on the 5-year fallow is blamed on its previous land use history of unintended bush fire which resulted in the burning of undergrowth and available litter. The bush fire may have burnt the seedlings or propagules which probably affected the rapid establishment of herbaceous species that would have provided cover to the soil as obtained on the farmland. This reason could be responsible for the very high micronutrient losses experienced on the 5-year fallow plot. This is consistent with the finding of Maret and Wilson (2005) that fire either unintended or prescribed burning have profound impacts on establishment rates by breaking seed dormancy and altering micro-environmental conditions for germination and growth.

The low micronutrient loss experienced on the 10-year old fallow is attributed to its dense vegetation structure. The vegetation structure (crown cover, girth and basal cover) on the 10-year old fallow and its high litter depth help to intercept a significant amount of rainwater, which afterward moves down as steam flow to the soil, helps to minimize micronutrient loss (Puigdefábregas, 2005). The high micronutrient loss recorded on the abandoned farmland at the early stage of the experiment (March to June) may be attributed to the scanty undergrowth (density of herbs) and absence of adequate vegetation cover to intercept the rainwater. The considerable reduction in the later period (July to November) than on the 5-year old fallow plot is attributed to the sprouting of cassava and rapid growth of herbs mostly *Chromolaena odorata*. Similar observation was reported by Vasquez-Mendez et al., (2010). The canopy gaps (open canopy structure) on the 5-year old fallow did not provide adequate cover for controlling soil erosion, as it gives way for raindrop to strike directly on the topsoil. This again corroborates the findings of Solaimani et al., (2009) and Su et al., (2010) that sites with sparse surface cover (vegetation and ground cover) can increase soil erosion. The rapid growth in herbaceous species and subsequent herbaceous cover on the abounded farmland and 3-year old fallow following the rains affords the soil adequate cover to minimize erosional losses.

The micronutrient element loss result reveals that Mn, Fe and Zn suffer more losses on all the plots. The losses of micronutrient indicate the following order Mn > Zn > Fe >Cu. The study shows that the 5-year fallow recorded the highest losses of micronutrient followed by the abandoned farmland. This indicates that the 5-year fallow is most susceptible to soil erosion, and loses the most micronutrients. This implies that large quantities of essential micronutrients may be lost in fallow soil with inadequate land cover protection. The variation in micronutrient elements in eroded sediment on all the plots is attributed to the quantity of sediment loss generated. The significance in total micronutrient lost in eroded sediment is verified by the result of analysis of variance. The results obtained show statistically significant variations in nutrient elements with the exception of Zn loss in eroded sediment on all the plots as noted above is attributed to the quantity of sediment loss. The low micronutrient loss recorded on the 10-year and 3-year fallow plots is an indication that increases in surface cover effectively reduces sediment loss. Thus, the low micronutrient loss experienced on these fallows is related to the small quantities of sediment eroded. The variation in micronutrient loss among the treatments underscores the importance of vegetation especially herbaceous cover in reducing the rate of sediment loss.

5. Conclusion

The study has shown the importance of density of herbs and herbaceous cover in controlling micronutrient losses during natural vegetation fallow. The study reveals that soil erosion occurs in vegetation fallows even with greater canopy cover resulting in the loss of topsoil nutrients. It is observed that fallows with greater vegetation characteristics records reduced micronutrient loss compared to fallows with sparse vegetation. The study reveals that July and August experience the highest amount of micronutrient losses. This implies that surface mulching and the planting of herbs on fallows with scanty undergrowth and vegetation cover should be carried out during these months to reduce unproductive loss of essential micronutrient elements from the soil layer. The substantial reduction in micronutrient losses with increasing rainfall events on the 10-year plot is symbolic of the importance of vegetation in promoting hydrological functioning in the environment. The study shows that soil erosion results in the loss of Mn, Fe and Zn which are important micronutrients required in small amounts by plants. It has also shown that herbaceous species such as *Chromolaena odorata* that regenerates naturally and quickly is able to reduce micronutrient loss as observed on the 3-year old fallow and abandoned farmland as such should be allowed to grow on farmland as well as planted on fallow with scanty herbaceous cover to provide cover.

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