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Quantification of soil and nutrient loss due to yam harvesting: A case study in two local government areas in Benue state, Nigeria.

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ABSTRACT

Soil loss due to crop harvesting is a recognized erosion process which has significantly contributed to soil degradation. Despite its significance, soil loss due to crop harvesting has been given little attention in Benue state and Nigeria at large. This is evident in the paucity of information on soil loss due to crop harvesting in Nigeria. Therefore a field experiment was conducted to quantify soil and nutrient loss due to yam harvesting in two local government areas (Kwande and Ushongo) of Benue state and to identify factors which could contribute to soil loss in these areas. Data collected on soil loss were subjected to t-test at $\alpha = 0.05$. Average crop yield in Kwande was 18.9 t ha^{-1} and 16.3 t ha^{-1}in Ushongo with corresponding soil loss of 3.26 t ha^{-1} harvest^{-1} and 1.97 t ha^{-1}harvest^{-1} respectively. Higher soil loss observed in Kwande compared to Ushongo can be attributed to higher crop yield and clay content of the soil. Crop yield, clay content and soil organic matter correlated positively with soil loss in Kwande ($r = 0.75$, $r = 0.58$, $r = 0.65$) while in addition to crop yield and clay content sand correlated negatively with soil loss in Ushongo ($r = 0.77$, $r = 0.60$, $r = -0.60$). Soil nutrient losses for nitrogen, phosphorus and potassium were significantly higher in Kwande compared to Ushongo by 2.71, 2.67 and 2.02 times respectively. The findings suggest that soil loss in these areas could degrade the land within a short time, especially where mono-cropping of yam is practiced. Farmers are therefore advised to hand-rub yam tubers while harvesting on the field and practice crop rotation.

1.0 Introduction

Soil loss due to crop harvesting (SLCH) has been widely recognized as a contributor to land degradation. In Sub-Saharan Africa with Nigeria inclusive, effort have been made to reduce soil erosion, particularly water and wind erosion. However, considerable soil masses are exported from cropped land during harvesting of root, tuber, bulb and some legume crops such as yam, cassava, onion and groundnut (Dada et al., 2016;Isabirye et al., 2007; Mwango et al., 2015). Soil and associated nutrients sticking to harvested crop that is removed from the field is referred to as soil loss due to crop harvesting (Poesen et al., 2018; Ruysschaert et al., 2004.). SLCH cause loss of valuable top soil and nutrients (Oshunsanya et al., 2018a; Oshunsanya et al., 2018b;Sumithra et al., 2013.). Mean SLCH has shown to be similar to that of water erosion in many countries of the world.(Oshunsanya et al., 2018b;Poesen et al., 2001).

SLCH is of great significance especially on gentle slopes and flat lands where there is lesser risk of water and wind erosion. For example Isabirye et al. (2007) reported SLCH of 3.4 t ha^{-1} due to harvesting of cassava. Similarly,Oshunsanya and Samson (2019) in a study reported SLCH of 1.3 t ha^{-1} for cassava in Nigeria. In another study Parlak et al. (2018) reported 4.00 Mg ha^{-1} average SLCH for celery. The severity of SLCH varies depending on several factors such as crop type, soil properties and harvesting technique amongst others. For instance, Faraji et al. (2017) suggested soil moisture content to be a contributor to SLCH, Similarly Oshunsanya et al. (2018b) suggested root hair density as a factor that could influence SLCH. In like manner crop age was attributed to be a factor responsible for SLCH (Isabirye et al., 2007).

Although SLCH has been documented for several crops in some countries of the world, however, it is still under reported in Nigeria. Furthermore there is paucity of information on SLCH across different Agro-ecological zones. In addition, despite being the largest producers of yam globally most farmers in Benue state are either unaware or underrate this process of erosion. Generally during harvesting of yams, the tubers are rarely cleaned on the field as a result, some quantity of soil is exported from the farm to the farmers house, storage facility and market place. Therefore this study was conducted to i. quantify soil loss due to yam harvesting. ii. estimate nutrient loss due to yam harvesting. iii. identify factors that contribute to SLCH in the study area.

2.0. Materials and methods

2.1 Study area

The study was conducted 2019 at Kwande and Ushongo local government areas in Benue State, Nigeria. The study location in Kwande lies between latitude 06˚ 88′ 50.10″ N and longitude 09˚ 24′ 41.30″ E.While Ushongo location lies between 06˚ 94′ 21.67″ N and longitude 09˚ 31′ 05.20″ E. Both locations have a mean annual rainfall of about 1400 mm. The rain generally starts from April and spans through the late October. The temperatures of the locations are generally high throughout the year with February and March as the hottest months.The soils of Kwande consist of masses of basement complex rocks and plateau of basaltic rocks. Soil texture in the study location was sandy clay loam at Kwande and sandy loam at Ushongo. The predominant crop grown in both locations are yam, millet and maize.

2.2 Sampling methodology

Crop and soil samples were taken when farmers were harvesting the crops. The harvested area was divided into 15 replicates in each location. Each sub-plot measured 5 m × 4 m (20 m^2). Yam was grown as a sole crop on mounds spaced at 1 m × 1 m. The average plant density was 10,000 plants per hectare. Harvesting was done at 8 months after planting. The harvested yam tubers were carefully dug out of the mounds using hoes. The tubers were weighed with soil attached and thereafter the tubers were rubbed and cleaned to remove the adhering soil (Fig 1). The soil was air-dried and weighed using a weighing scale. The soil samples collected were then packed into polythene bags and taken to the laboratory for nutrient analysis. Soil samples were also collected from each subplot to determine the soil physical and chemical properties at harvesting.

2.3 Soil analysis

Soil samples were collected from each subplot at 0–30 cm depth at harvesting. Disturbed soil samples were collected with a soil auger, while 5 cm × 5 cm cylindrical cores were used to take undisturbed soil samples for assessment of baseline and post-harvest status of the soil and treatment effects on soil properties. The soil pH was measured in a 1:1 ratio mixture of soil and distilled water (Mclean, 1982). The soil organic carbon content was determined using the Walkley-Black wet-oxidation method (Walkley and Black,1934) as described by Nelson and Sommers (1982), while the total nitrogen content was determined using the macro-kjeldahl digestion-distillation apparatus following Bremmer and Mulvaney (1982) procedure. Melich III was used to extract the soil available phosphorus and the absorbance was read using the spectrophotometer (Olsen and Sommers, 1982).The soil exchangeable acidity was determined using the KCl extraction method, while the exchangeable bases were determined using neutral ammonium acetate as the extractant (Rhodes, 1982). Calcium and magnesium were determined from the extract by 0.01 M EDTA titration method, while sodium and potassium were determined using the flame photometer (Jackson, 1970). The soil Fe, Cu, Mn, and Zn contents were determined using the hydrochloric acid procedure as described by Rhodes (1982). The particle size distribution of the soil was determined using Bouyoucos hydrometer method as described by Gee and Or (2002). After oven-drying the soil samples to constant weight at 105°C, the soil bulk density was computed as described by Grossman and Reinsch (2002). Gravimetric moisture content was also computed as described by Grossman and Reinsch (2002).

2.4 Soil loss determination

The soil loss value per unit of crop mass (SLCHspec), the total soil loss for a given crop per unit area (SLCHcrop) and nutrient losses were determined as outlined by Ruysschaertet al. (2004; 2007).

2.4.1 Soil loss per unit of crop mass ($SLCH_{spec}$)

The soil loss value per unit of crop mass ($SLCH_{spec}$) was calculated using

$$\text{SLCHspec}(\text{kg kg}^{-1}) = \frac{M_{ds} + M_{rf}}{M_{crop}} \qquad (1)$$

Where Mds = mass of exported air-dried soil in kg, Mrf= mass of rock fragments (kg) and Mcrop= net crop mass (kg). In this study, Mrf was zero, because harvesting was done manually, not involving removal of stones from the field. The Mcrop was not equal to the net crop mass as proposed by Ruysschaertet al. (2004) but equaled gross crop mass (silt + crop) because the accuracy of the field balance could not measure the difference between net and gross crop mass.

2.4.2 Soil loss due to crop harvest ($SLCH_{crop}$)

SLCHcrop was calculated using

$$\text{SLCHcrop}(\text{t ha}^{-1}\text{ harvest}^{-1}) = \text{SLCHspec} \times \text{Mcy} \qquad (2)$$

Where Mcy = crop yield (t ha^{-1} $harvest^{-1}$)

2.4.3 Soil nutrient loss estimation

Nutrient loss through crop harvesting was expressed on elemental basis and was estimated using the following equation:

Nutrient loss (kg ha^{-1} $harvest^{-1}$) = Nutrient content (g kg^{-1} soil) × 10 × $SLCH_{crop}$ (t ha^{-1} $harvest^{-1}$).

2.5 Data analysis

Data collected were subjected to a normality test (Leven's test) to verify the distribution pattern of the variables before subjecting to statistical analysis. Data were normally distributed for both locations. Data on tuber yield, soil loss, soil properties and soil nutrient loss were subjected to t – test at $\alpha = 0.05$ using GenStat 17^{th} edition. Pearson's correlation coefficients and significance levels were determined between dependent variables (SLCHcrop and SLCHspec) and independent variables (yam tuber yield, moisture content, bulk density, sand, silt, clay, soil organic matter)..

3.0. Results and Discusion

3.1 Soil loss due to yam harvest

SLCHspec due to yam harvest in Kwande and Ushongo was not significantly ($P > 0.05$) different (Table 1). However SLCHspec was slightly higher in Kwande compared to Ushongo by 41.7%. In contrast, SLCHcrop was significantly ($P < 0.05$) higher in Kwande compared to Ushongo by 65.5%. This difference could be attributed to the significant difference in tuber yield. Yam tuber yield was observed to be considerably higher for Kwande than Ushongo. Several researches have reported crop yield to directly influence SLCH (Faraji et al., 2017;Oshunsanya et al., 2018a; Parlak et al., 206; Ruysschaert et al., 2007.). For instance Oshunsanya and Samson (2019) in an experiment reported crop yield to be responsible for differences in SLCH between four cassava varieties. Higher yield observed in Kwande could be as a result of the higher inherent soil nutrient status of the soil in Kwande (Table 2). Oshunsanya et al. (2018b) reported increase in yam yield as a result of increase in soil nutrients through fertilizer application

Another factor that may be responsible for the higher SLCH in Kwande could be the higher clay content observed in Kwande (Table 1). Clay particles through its properties could adhere more to rough tubers consequently causing more soil to be attached to the harvested tubers. Therefore as clay content increases SLCH is expected to increase. This finding is in agreement with the result of Dada et al (2016) who reported that much soil loss was observed in area with higher clay content compared to area with lower clay content during yam harvesting. In another experiment, Parlak et al. (2016) reported a similar result of clay content as a major contributor to SLCH during harvesting of carrot in Turkey.

Table 1 Soil loss due to yam harvesting and related soil properties of yam plots in Kwande and Ushongo

	Kwande	Ushongo	
Parameter	Mean (min-max)	Mean (min-max)	P value
SLCHspec (kg kg^{-1})	0.17(0.09-0.33)	0.12(0.05-0.24)	Ns
SLCHcrop (t ha^{-1} $harvest^{-1}$)	3.26(1.50-5.90)	1.97(1.00-4.50)	0.003
Yam yield (t $ha^{-1}harvest^{-1}$)	18.90(14.5-21.2)	16.32(14.4-24.0)	0.002
Sand (g kg^{-1})	661.70(535.2-716.4)	696.40(669.2-715.2)	Ns
Silt (g kg^{-1})	109.50(66.80-130.00)	119.00(90.00-140.00)	Ns
Clay (g kg^{-1})	228.80(163.60-358.00)	184.60(152.00-230.80)	0.002
Bulk density (Mg m^{-3})	1.41 (1.40-1.44)	1.42(1.40-1.46)	Ns
Gravimetric moisture content (%)	2.00(0.90-4.00)	2.32(0.70-5.00)	Ns
Soil organic carbon (g kg^{-1})	23.09(19.60-31.10)	7.96(5.40-9.40)	<0.001
Soil organic matter (g kg^{-1})	39.81(33.79-53.62)	13.72(9.31-16.21)	<0.001

min-max= minimum-maximum; ns= not significant

Table 2 Soil nutrient status of the experimental fields

	Kwande	Ushongo	
Parameter	Mean (min-max)	Mean (min-max)	P value
Nitrogen (g kg^{-1})	1.01(0.84-1.20)	0.73(0.43-0.92)	<0.001
Phosphorus (mg kg^{-1})	4.42(3.86-4.90)	3.34(2.96-3.80)	<0.001
Potassium(cmol kg^{-1})	0.25(0.22-0.28)	0.24(0.21-0.28)	Ns
Calcium (cmol kg^{-1})	2.95(2.78-3.10)	2.82(2.70-3.10)	0.012
Sodium (cmol kg^{-1})	0.22(0.19-0.25)	0.22(0.20-0.26)	Ns
Magnesium (cmol kg^{-1})	2.81(2.68-2.92)	2.69(2.50-2.84)	0.019

min-max= minimum-maximum; ns= not significant

3.2 Soil nutrient loss due to yam harvest.

Nitrogen, phosphorus and potassium losses were significantly ($P<0.05$) different (Table 3). Mean soil nutrient loss due to yam harvest showed that nitrogen, phosphorus and potassium losses were higher for Kwande compared to Ushongo by 2.71, 2.67, 2.02 times respectively. Higher nutrient loss observed for Kwande compared to Ushongo can be ascribed to differences in crop yield and inherent soil nutrient content (Table 2) because soil nutrient loss is a product of SLCH and nutrient content. The higher yield in Kwande resulted to higher soil loss thus affecting soil nutrient loss indirectly. Soil organic matter is another factor that could be responsible for the differences in soil nutrient loss. Soil organic matter plays an important role in improving nutrient retention which could consequently lead to increase in nutrient content of the soil. In this study, organic matter content was observed to be significantly higher at Kwande (Table 1). This could be the reason for the higher nutrient content and consequently higher nutrient loss. A similar observation was made by Isabirye et al. (2007) who reported differences in soil nutrient losses for cassava and sweet potato was partly as a result of crop yield. In another experiment, Mwango et al. (2015) attributed differences in crop yield and inherent fertility status of the top soil to be responsible for differences in nutrient losses due to crop harvest for different crops and in different villages. Average soil nutrient loss due to crop harvest in this study was higher than losses reported for sweet potato (0.14 kg N ha^{-1}, 0.01 kg P ha^{-1} and 0.15 kg K ha^{-1}) by Isabirye et al. (2007) and sugar beet (3.35 kg N ha^{-1}, 0.04 kg P ha^{-1} and 4.80 kg K ha^{-1}) by Faraji et al. (2017). These differences could be ascribed to differences in soil structure, texture and top soil nutrient concentration.

Table 3 Soil Nutrient Losses due to Yam Harvesting

	Kwande	Ushongo	
Parameter	Mean (min-max)	Mean (min-max)	P value
Nitrogen (kg ha^{-1})	36.69(19.00-70.80)	13.35(7.31-21.84)	<0.001
Phosphorus (kg ha^{-1})	0.16(0.08-0.29)	0.06(0.04-0.09)	<0.001
Potassium (kg ha^{-1})	8.99(4.37-15.34)	4.46(2.70-5.88)	0.003

min-max= minimum-maximum; ns= not significant

3.3 Relationship between SLCH, crop yield and soil properties

Table 4 and 5, shows relationship between soil loss (SLCHspec and SLCHcrop) and crop yield and soil properties. At Kwande, positive significant ($P<0.05$) relationship was observed between SLCHspec and crop yield ($r = 0.70$), clay ($r = 0.54$) and soil organic matter ($r = 0.62$) (Table 4). A similar trend was observed in Ushongo, significant positive

(P<0.05) relationship was observed between SLCHspec and crop yield (r = 0.73) and clay (0.56). On the other hand a negative significant (P<0.05) relationship was observed between SLCHspec and sand (r = 0.56) (Table 5). This implies that as crop yield increases, soil loss could increase as well. This is because crop yield increase could be in terms of higher number of tubers and size moreover this could translate to more tubers surface to which soil can adhere.

Increase in clay content leads to decrease in sand content. Therefore increase in clay content could imply increase in finer and smaller soil particles with higher surface area which could easily stick to tubers as against coarse and larger soil particles. This can be further explained by the negative correlation observed between sand and clay in both locations (Table 4 and 5). The positive relationship between SLCH with crop yield and clay could be partly responsible for the difference in SLCH between the two locations. Kwande was observed to have significantly higher yield and clay content compared to Ushongo. Similar observation has been reported by some researches (Dada et al., 2016; Mwango et al., 2015; Ruysschaert et al., 2006.). For instance, Li et al. (2006) in an experiment reported that SLCH was related to clay content for sugar beet. Similarly, Parlak et al. (2016) in another experiment reported crop yield and soil moisture content in addition to clay to greatly influence soil loss during carrot harvesting. In contrast soil moisture content in this study had no significant relationship with soil loss. This could be as a result of the little variation in soil moisture. Moreover, yam was harvested in the dry season when the soil moisture content was low. This could have contributed to why no significant relationship was observed between soil moisture and SLCH.

Table 4 Pearson correlation coefficient between SLCH parameters, crop yield and soil properties at Kwande

	SLCHcrop	Crop yield	Sand	Clay	Silt	SOM	BD	GM
SLCHspec	0.98**	0.70**	-0.36	0.54*	-0.42	0.62*	-0.11	0.16
SLCHcrop		0.75**	-0.39	0.58*	-0.40	0.65*	-0.16	0.21
Crop yield			-0.53*	0.67*	0.77**	0.60*	-0.09	0.11
Sand				-0.97**	0.25	0.31	0.18	-0.19
Clay					-0.48	0.35	-0.32	0.25
Silt						0.28	0.16	0.32
SOM							-0.36	0.18
BD								-0.12

**= significant at 0.01; *= significant at 0.05; SOM = soil organic matter; BD = bulk density; GM = gravimetric moisture content

Table 5 Pearson correlation coefficient between SLCH parameters, crop yield and soil properties at Ushongo

	SLCHcrop	Crop yield	Sand	Clay	Silt	SOM	BD	GM
SLCHspec	0.91**	0.73**	-0.55*	0.56*	-0.34	0.31	-0.12	0.23
SLCHcrop		0.77**	-0.60*	0.60*	-0.37	0.39	-0.21	0.27
Crop yield			-0.47	0.13	-0.05	0.37	-0.41	0.35
Sand				-0.89**	0.20	-0.54*	0.43	-0.17
Clay					-0.83	0.43	-0.35	0.06
Silt						0.17	0.19	0.36
SOM							-0.42	0.25
BD								-0.12

**= significant at 0.01; *= significant at 0.05; SOM = soil organic matter; BD = bulk density; GM = gravimetric moisture content

Figure 1: Pictorial view of weighing of yam and soil loss.

3.5 Implication of soil loss due to crop yam harvesting

Average soil loss due to yam harvesting in this study was about 2.62 t ha^{-1} $harvest^{-1}$. Losses of such magnitude must not be neglected, as continuous removal of soil in this quantity will lead to a rapid decline in soil productivity and land degradation. Where crop yield and soil moisture condition is higher, the soil loss could even be higher in quantity. Benue state is the largest producers of yam in Nigeria. Assuming about 3.5 million metric tons of yam is produced annually, this implies about 5.25×10^4 tons of soil could be removed during harvesting of yam. This could affect the sustainability of the soil especially where mono-cropping of yam is practiced.

Another implication of soil loss is the associated nutrients removed during the process. Hence nutrient loss will reduce the farmer's financial benefit in terms of cost of replacing the nutrients. In most cases, after harvesting of yams, farmers transport their yams directly to houses, markets or storage facilities without removing the adhering soil. These soils are further washed into canals and drainage from the market and houses, thus contributing to environmental pollution as nutrients from the soil could be discharged into water bodies. Yu et al. (2016) reported that about 3% and 20% of nitrogen and phosphorus loads in water bodies comes from soil nutrient loss. Continuous discharge of nutrients into water bodies could contaminate water and also cause turbidity, which could pose a great threat to aquatic organisms.

4.0 Conclusion

Soil loss due to yam harvesting was higher in Kwande compared to that of Ushongo. This can be attributed to difference in crop yield and clay content of both locations. As a result, soil nutrient losses due to yam harvesting in Kwande were also higher compared to Ushongo. Soil loss due to yam harvesting will not only lead to rapid degradation of the field but will also reduce the farmer's financial benefit. Therefore farmers are advised to shake and hand-rub yam tubers while harvesting. In addition it is suggested that farmers practice crop rotation with cereals and legumes which may not have the tendency of causing soil loss.

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