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Influence of fertilizer application on soil and nutrient loss during carrot harvesting

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ABSTRACT

Soil loss from root crop harvesting is a significant erosion process contributing to soil degradation. While organic fertilization could promote soil structure and reduce soil loss, the variation in the effectiveness of different organic fertilizers vis-a-vis inorganic fertilization remains unclear. Such understanding is critical for adequate soil management for reducing harvest-related soil loss. A two-year field-based study was carried out to compare the effect of two commonly used organic amendments and inorganic fertilizer on carrot yield and harvest-related soil loss. Treatments included a control, inorganic fertilizer, pig manure, and poultry manure; with each manure applied at a rate to supply 60 kg K ha^{-1}. Compared to the control where the average soil loss for the two years was 1.21 t^{-1} ha^{-1} harvest $^{-1}$, inorganic fertilization induced a soil loss of 2.70 t^{-1} ha^{-1} harvest $^{-1}$, while 1.94 t^{-1} ha^{-1} harvest $^{-1}$ and 1.87 t^{-1} ha^{-1} harvest $^{-1}$ of soil was lost under poultry manure and pig manure amendments, respectively. The higher soil loss in the fertilized treatments compared to the control was attributed to the higher crop yields. However, the reduced soil loss in organic amendments compared to the inorganic fertilizer was due to more improved soil aggregation. Also, higher nutrient uptake arising from the increased yield resulted in significant loss of soil nitrogen, phosphorus, potassium, and calcium in the second year. Higher carrot yield due to fertilization is associated with higher soil removal, especially under inorganic fertilization. It is suggested that cleaning carrot roots during harvesting will ensure minimal soil loss.

Keywords: Soil loss, Nutrient loss, Crop yield, Degradation, Fertilization

INTRODUCTION

Soil erosion is regarded as the most prominent process of land degradation. Reports warn that by 2050 it could lead to about a 10 percent loss in crop production and an estimated removal of 75 billion tons of soil (FAO, 2022). Therefore, to achieve food security and soil sustainability focus has been on ways to mitigate and reduce soil erosion from agricultural lands. Many erosion studies have focused on water and, to a lesser extent, wind and tillage erosion (Panagos *et al*., 2019; Parlak *et al*., 2021). However, soil loss from crop harvesting (SLCH) has received little attention despite its importance and severity. SLCH has been shown in studies to be a significant contributor to soil degradation, particularly in areas where root, tuber, bulb, and pod crops are grown and on flat lands where water erosion is minimal (Oshunsanya, 2016a; Faraji *et al*., 2017; Parlak *et al*., 2018; Oshunsanya *et al*., 2022a). As a result, in order to achieve the United Nations' sustainable development goal of zero hunger and zero land degradation, all land degradation processes, including SLCH, must be identified and understood.

SLCH is described as loose soil, soil clods, and rock fragments that stick to crops and are exported and transported with harvested crops (Ruysschaert *et al*., 2004; Ruysschaert *et al*., 2006a; Oshunsanya, 2016b; Parlak *et al*., 2018; Panagos *et al*., 2019 and Samson and Ityavnongo, 2021). Such crop includes carrot (*Daucus carota* L.), cassava (*Manihot esculenta* C.), garlic (*Allium sativum* L.), peanut (*Arachis hypogaea* L.), potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* L.) and yam (*Dioscorea rotundata*). SLCH does not only cause topsoil depletion but can also cause losses of essential plant nutrients and soil organic carbon, consequently reducing soil fertility and productivity (Ruysschaert *et al*., 2006b; Oshunsanya *et al*., 2022). Previous studies have reported several factors as key drivers of variation in SLCH. Some of these factors which have been studied extensively include soil properties (texture, structure, moisture content; (Ruysschaert *et al*., 2007a; Isabirye *et al*., 2007 and Parlak *et al*., 2018), crop factors (crop yield, crop morphology (Ruysschaert *et al*., 2007b; Sumithra *et al*., 2013; and Oshunsanya *et al*., 2019) and harvesting technique (Tuĝrul *et al*., 2012). On the other hand, other factors, such as agronomic and management practices (Oshunsanya *et al*., 2022b) that could affect the soil and crop, thereby influencing SLCH, have been under-studied. Moreover, how soil amendment practices influence SLCH has not received adequate attention. Therefore, it is necessary to fully understand how these factors could affect SLCH to take precautions and adopt the best management practices for sustainable crop production.

Carrot (*Daucus carota* L.) is a biennial root vegetable that belongs to the Apiaceae family. It is widely grown throughout the world in temperate, tropic, and subtropical climates (Bose and Som, 1990). Because of their nutritional content, such as protein, carbohydrates, fiber, thiamine, riboflavin, iron, calcium, phosphorus, and vitamins C, K, B1, B2, B6, carrots are considered one of the essential vegetables in human nutrition for improved growth (Pant and Manandhar, 2007; Arscott and Tanumihardjo, 2010; Sharma *et al*., 2012). Generally, carrot production can be a profit-rewarding enterprise for small-scale, resource-constrained farmers because it is a short-duration crop with higher yields per unit area (Ahmad *et al*., 2005). Due to the depleted soil fertility and poor resource use by farmers in many developing countries, the yield of carrot is below the recommended average (Ahmed *et al*., 2014). Hence, many carrot growers have used organic (manure) and inorganic fertilizers. Hence, the use of organic (manure) and inorganic fertilizers to improve carrot yield has become a widespread practice. Consequently, the positive impacts of farmyard manure on the growth of carrots have been reported in soils with low fertility in developing countries such as Nigeria (Ahmed *et al*., 2014). Similarly, Agbede (2021) reported an increase in carrot root yield from poultry manure-fertilized and inorganic-fertilized carrots. However, there remains an urgent need to evaluate the annual changes in soil physicochemical properties and the amount of post-harvest soil loss associated with the growth response of carrots and changes in soil physicochemical properties to organic and inorganic fertilization.

Evidence has shown that during carrot harvesting, a significant amount of soil is exported from the farm (Mwango *et al*., 2015 and Parlak *et al*., 2016). For instance, Parlak *et al*. (2016) reported SLCH of 14.0 and 22.4 Mg ha^{-1} due to mechanically and manually harvested carrots in Turkey. Similarly, Mwango *et al*. (2015) estimated an SLCH of 7.1 Mg ha^{-1} resulting from carrot cultivation in Tanzania. However, how fertilization types or sources regulate the amount of soil mass and nutrient loss remains uncertain. Notably, the physical and chemical properties of soils can be significantly altered, depending on the fertilization regime imposed on them (Haynes and Naidu, 1998), which could, in turn, impact the magnitude of SLCH. The repeated application of these fertilizer sources could have differing impacts on the changes in soil physicochemical properties, which could regulate the amount of soil loss in consecutive years of carrot cultivation and harvesting. Unfortunately, the exact impact of different fertilization types (organic vs. inorganic) on SLCH after repeated application in two successive years remains unresolved. This signifies a significant research gap in understanding the changes in soil properties and the associated impact on the growth of carrots to influence soil loss in cultivated fields. Therefore, it is essential to understand factors that regulate soil and nutrient loss under continuous organic and inorganic fertilization and to develop strategies for conserving soil resources while improving crop yield in soils under continuous cultivation.

We hypothesized that different organic and inorganic fertilizers would affect factors influencing soil loss due to crop harvesting, thereby causing changes in soil loss. Therefore, the objectives of this experiment were to (1) evaluate the impact of applying different organic and inorganic fertilizers on soil and nutrient loss due to carrot harvesting and (2) explore factors that regulate changes in soil properties inducing soil loss.

MATERIALS AND METHODS

Study Area:

This study was carried out during the 2020 and 2021 growing seasons at the Teaching and Research Farm of the Department of Soil Science, Federal University of Agriculture, Makurdi, situated on the north-bank side of the River Benue. The site lies between latitude 07° 47'14.8''N and longitude 08° 37' 29.5''E with an elevation of 97 m above sea level (Figure 1). Makurdi falls within the tropical climate with clearly distinct dry and rainy seasons. The rainy season lasts from April to October, with the dry season lasting five months (November to March). The average annual rainfall is 1140 mm yr-1 (Agada *et al*., 2016). The mean annual temperature ranges from 29 – 32 °C. February and March are marked as the hottest months. The soils of the area are formed predominantly from Makurdi sandstones and are well-drained. Before the commencement of this experiment, maize and melon was grown on the soil of the experimental area for three years; manure and inorganic fertilizers were applied throughout this period. A period of fallow was allowed one year before the commencement of this experiment. At the commencement of this experiment, soil texture was sandy loam, bulk density was 1.35 g cm^{-3}, pH was 5.92, organic carbon and total nitrogen was 21.00 and 1.60 g kg^{-1}. The content of soil available phosphorus and potassium were 8.15 mg kg^{-1} and 0.25 cmol kg^{-1} respectively.

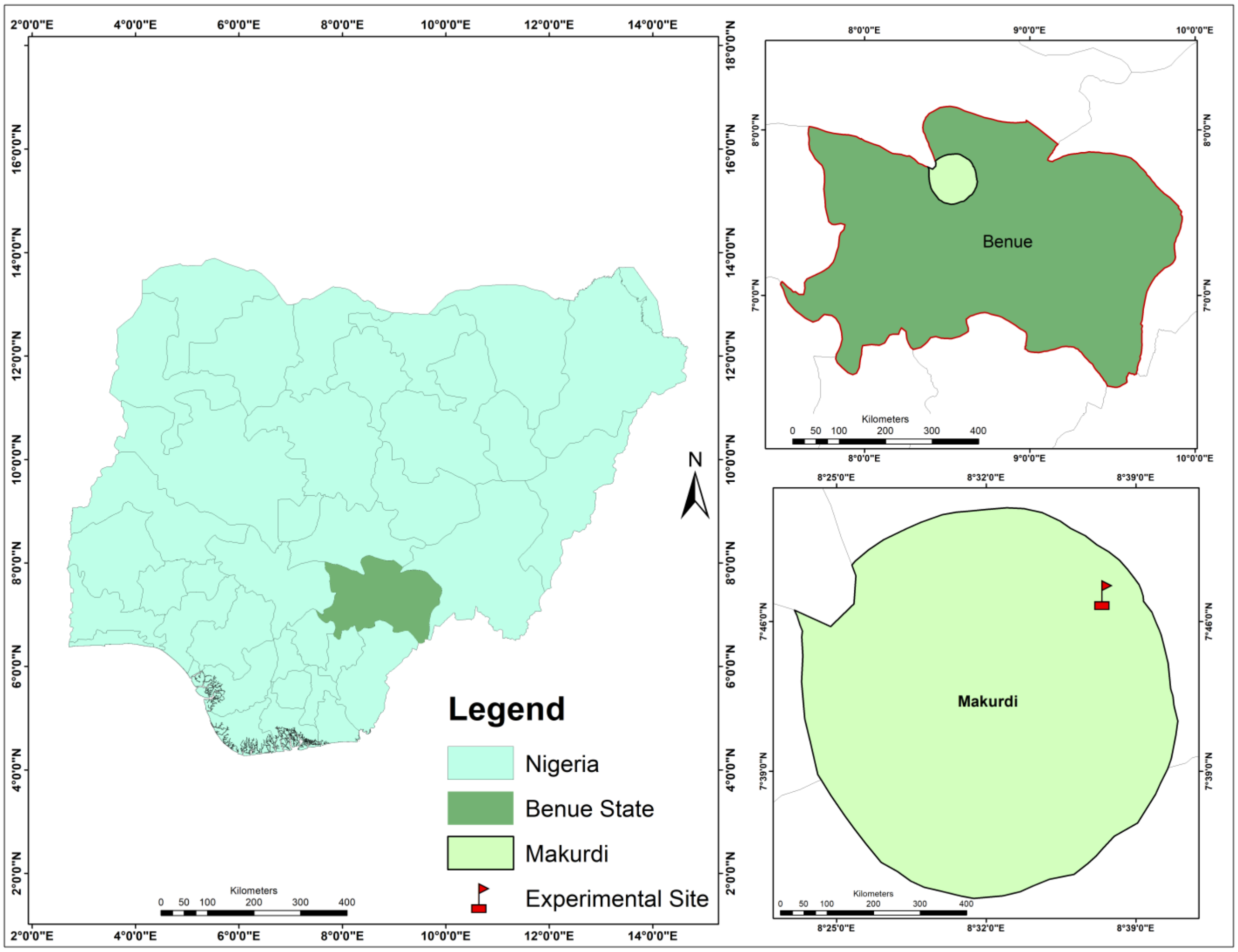

Fig. 1 Map showing the location of the experimental site

Experimental Design and Treatments:

The experimental land was manually cleared of all vegetation. The experiment comprised four (4) treatments: control (no fertilizer), inorganic fertilizer, poultry manure, and pig manure, respectively. Treatments were laid out on a randomized complete block design and replicated four times. The fertilizer application rate used to calculate the quantity of fertilizer applied was 60 kg K ha^{-1}. Inorganic fertilizer was applied to treatments requiring inorganic fertilization at the rate of 120 kg ha^{-1} and 70 kg ha^{-1} NPK 15-15-15 and muriate of potash (MOP), supplying 30% and 70% of the required fertilizer rate. NPK was applied two weeks after planting, while MOP was applied six weeks after planting. Also, 9.8 t ha^{-1} and 11.3 t ha^{-1} pig manure and poultry manure were applied to some plots to supply the 60 kg K. The poultry and pig manure used were sourced from the Animal Teaching and Research Farm of the Federal University of Agriculture, Makurdi. Application of manure was done two weeks before planting. The nutrient composition of the manure is shown in table 1. The carrot was sown on raised seed beds constructed manually with the use of a hoe. Each bed measured 5 m x 4 m (20 m^2) with an alley of 1 m between each bed. Inter-row spacing of 25 cm and intra-row spacing of 10 cm was maintained in each bed. The variety of carrot used as Nantes. Weeding was done every two weeks until harvest. The same procedure was repeated in the second year.

Table 1. Chemical composition of the manure used in the experiment

Property	Pig Manure	Poultry Manure
N (%)	1.67	1.82
P (%)	1.78	1.54
K (%)	0.61	0.53
C (%)	15.54	11.13

N, nitrogen; P, phosphorus; K, potassium; C, carbon.

Soil Sampling and Analysis:

Soil samples were collected randomly from the field before the commencement of the experiment to determine the soil properties before planting. Subsequently, soil samples were collected at harvest (2020 and 2021) to ascertain the soil status. Three soil samples were collected from each treatment in each replication from 0-30 cm depth using a bucket soil auger. In addition, a cylindrical core was used to collect soil samples for bulk density and moisture content determination. Soil samples were further air-dried and sieved using a 2 mm and 0.5 mm sieve and analyzed for chemical properties. The soil's particle size distribution was determined using the Bouyoucos hydrometer method as described by Gee and Or (2002). Grossman and Reinsch (2002) procedure were used for calculating soil bulk. Similarly, the gravimetric moisture content was determined using the Grossman and Reinsch (2012) method. The pH of the soil was measured using a pH meter in a 1:1 mixture of soil and distilled water (Mclean, 1982). Soil organic carbon content was determined using Walkley-Black wet-oxidation method described by Nelson and Sommers (Nelson and Sommers, 1982). The total nitrogen content was determined using a macro-Kjeldahl digestion-distillation-titration apparatus and the Bremmer and Mulvaney procedure (Bremner and Mulvaney, 1982). Melich III was used to extract available phosphorus, and a spectrophotometer was used to measure absorbance (Olsen and Sommers 1982). Exchangeable potassium was extracted using 1 N ammonium acetate (NH_4OAc) and further measured with flame photometer (Rhodes, 1982).

Harvesting and Soil Loss Collection:

Carrot was planted in the first year on May 14, 2020, and harvested on August 15, 2020. Planting was done again in the second year, on May 21, 2021, and harvested on August 20, 2021. Harvesting was carried out manually by carefully uprooting the carrot plants from the soil. The roots were gently separated from the stem and leaves. Roots were cleaned thoroughly to remove the adhering soil (Fig. 2). Fresh carrot root yield on plot basis was measured on the field using a weighing scale. Soils adhering to the roots were air-dried, weighed, and analyzed for N, P, K, and organic carbon content.

Fig. 2 Harvested carrots from field. (a) freshly harvested carrots before cleaning loose soil (b) cleaning of carrot roots.

Soil and Nutrient Loss Determination:

The soil loss value per unit of crop mass (SLCHspec) and the total soil loss for a given crop per unit area (SLCHcrop), were estimated using equations 1 and 2 below, as described by Ruysschaert *et al*. (2004). Nutrient losses were determined as outlined by Parlak and Blanco-Canqui (2015) and Faraji *et al*. (2017) using equation 3 below:

$$SLCHspec\ (kg\ kg^{-1}) = (Ms + Mrf)/\,(Mcrop) \qquad (1)$$

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

$$Nutrient\ loss\ (kg\ ha^{-1}\ harvest^{-1}\ ) = Nutrient\ content\ (\ g\ kg^{-1}\ soil) \times SLCHcrop \qquad (3)$$

Where Ms denotes the mass of exported air-dried soil (kg), Mrf denotes the mass of rock fragments (kg), and Mcrop denotes crop mass (kg). Mrf was zero in this study because harvesting was done manually, without the removal of stones from the field. Mcy denotes crop yield (t ha^{-1} $harvest^{-1}$).

Statistical Analysis:

All data collected on soil loss, soil nutrient loss, carrot root yield, and soil physical and chemical properties at harvest were subjected to statistical analysis using R v4.1.3 (R Studio Team, 2022). Analysis of variance was carried out to test significant treatment effects. Significant means were separated using the Duncan's multiple range test (DMRT) at 5% probability level. Data collected for both 2020 and 2021 for all the treatments were pooled as one and used for correlation analysis between soil loss variables and soil properties.

RESULTS

Effect of Fertilizer Application on Soil Loss and Carrot Root Yield:

The application of fertilizer significantly influenced soil loss due to carrot harvesting in the two years of study (Fig. 3 and 4). SLCHspec was significantly higher for the inorganic fertilizer treatment compared to the manure fertilized and control treatments (Fig. 3). In year one, SLCHspec resulting from inorganic fertilization was higher by 65%, 26%, and 31% compared with control, poultry manure, and pig manure respectively. Similarly, in the second year, SLCHspec was higher in the inorganic fertilized plots, whereas the lowest SLCHspec was observed in the control.

Total soil loss (SLCHcrop) significantly increased with the application of inorganic fertilizer, poultry manure, and pig manure compared with the unfertilized (control) treatment (Fig. 4). In the first year, SLCH crop was significantly in the fertilized plots compared to the control by 144% (inorganic), 70% (poultry manure), 62% (pig manure) respectively. A similar trend was observed in the second year, where fertilizer application resulted in significantly higher SLCHcrop compared to the control by 105% (inorganic), 51% (poultry manure), and 47.82% (pig manure), respectively. Generally, among the fertilizer treatments, inorganic fertilizer application resulted in higher soil loss (both SLCHspec and SLCHcrop) compared to manure application.

Fertilizer application significantly increased carrot fresh root yield in the two years of study (Fig. 5). In year one, fresh root yield from the fertilized plots was significantly higher compared to the unfertilized control by 48% (inorganic), 30% (poultry manure) and 29% (pig manure) respectively. Similarly, in year two, fresh root yield was significantly higher in the fertilized plots compared to the control by 85% (inorganic), 56% (pig manure), and 50% (poultry manure), respectively. Comparing the fertilizer treatments, inorganic fertilizer application resulted in higher root yield compared to both pig and poultry manure application by 15 and 18% (pig manure) and 13 and 23% (poultry manure) in the two years of study, respectively.

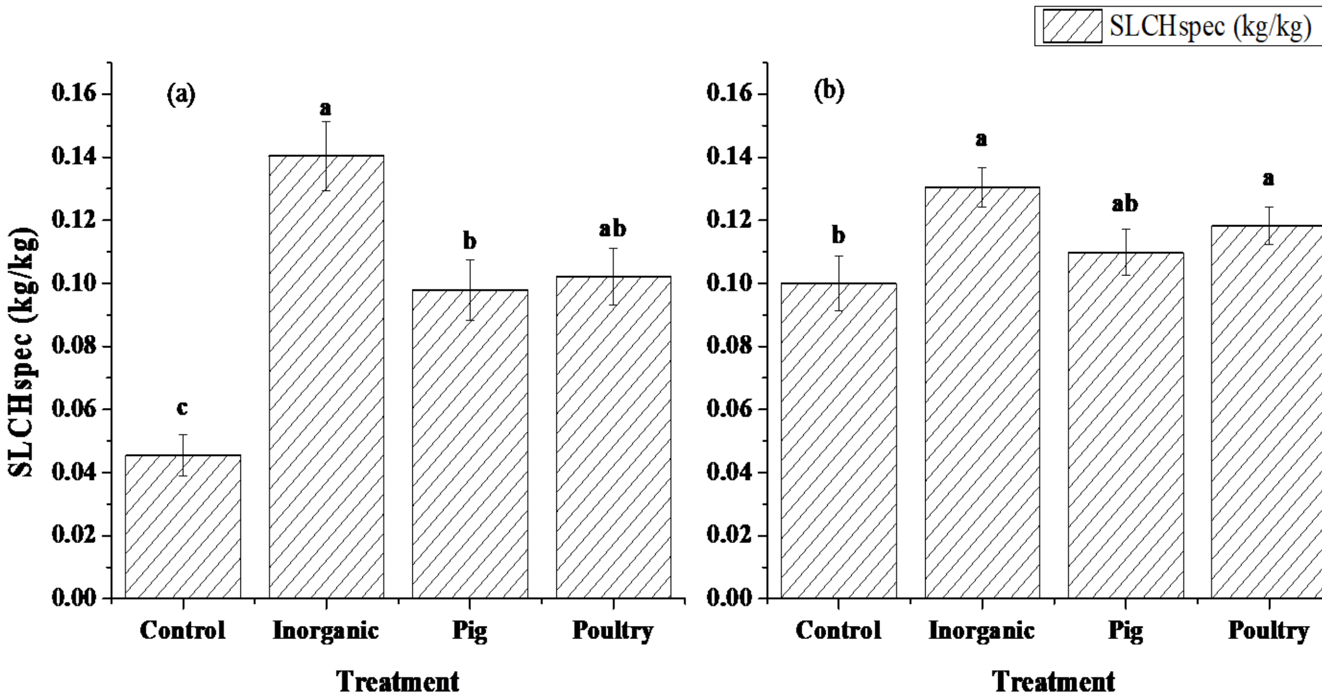

Fig. 3 Effect of inorganic fertilizer and manure application on mass specific soil loss (SLCHspec) due to carrot harvesting in 2020 (a) and 2021 (b). Each bar represents the mean ± SE. Letter on each bar indicates significant difference at P<0.05. Inorganic, NPK fertilizer; Pig, pig manure; Poultry, poultry manure

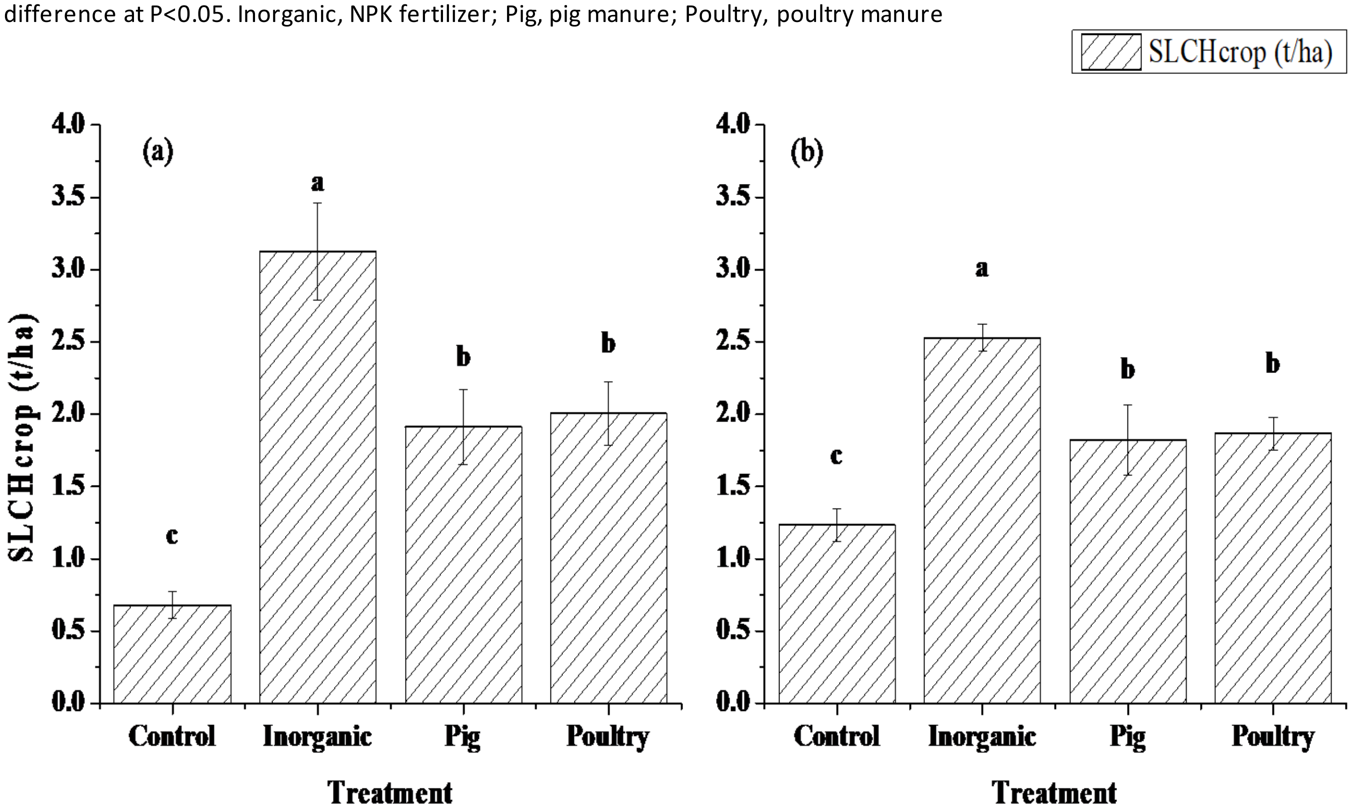

Fig. 4 Effect of inorganic fertilizer and manure application on total soil loss (SLCHcrop) resulting from carrot harvesting in 2020 (a) and 2021 (b). Each bar represents the mean ± SE. Letter on each bar indicates significant difference at P<0.05. Inorganic, NPK fertilizer; Pig, pig manure; Poultry, poultry manure

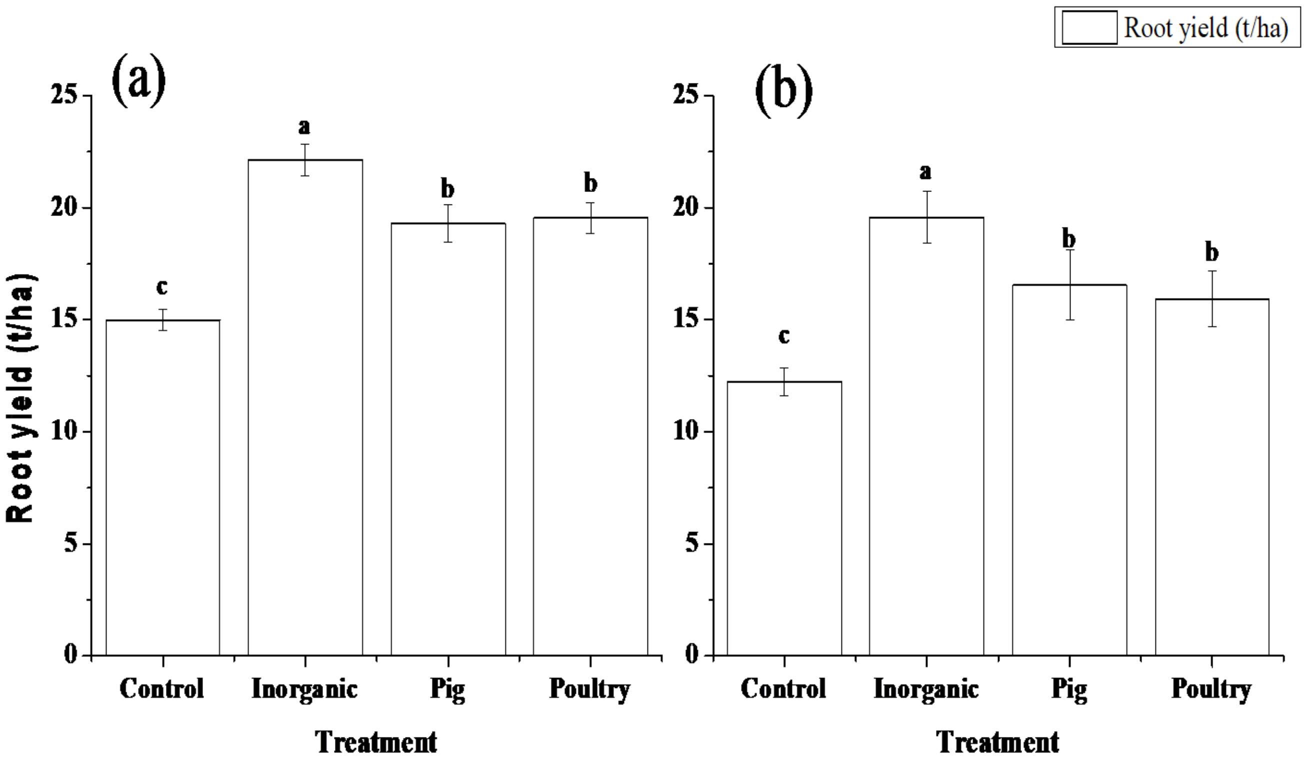

Fig. 5 Effect of inorganic fertilizer and manure application on carrot fresh root yield in 2020 (a) and 2021 (b). Each bar represents the mean ± SE. Letter on each bar indicates significant difference at P<0.05. Inorganic, NPK fertilizer; Pig, pig manure; Poultry, poultry manure

Effect of Fertilizer Application on Soil Nutrient Loss Resulting from Carrot Harvesting:

Soil nutrient losses associated with carrot harvesting showed soil organic carbon (OC), nitrogen (N), phosphorus (P), and potassium (K) losses were significantly higher under fertilizer application compared to the control (Table 2). Organic carbon loss was higher for fertilized plots compared to the control by 213 and 184% (inorganic fertilizer), 186 and 217% (pig manure), and 186 and 224% (poultry manure), respectively, for the both years of study. In like manner, N loss under fertilizer application was significantly higher compared to the control by 223 and 195% (inorganic fertilizer), 141 and 149% (pig manure), and 168 and 173% (poultry manure), respectively. Further fertilizer application resulted in significantly higher P loss compared to the control by 200 and 400% (inorganic fertilizer), 128 and 325% (pig manure), and 143 and 350% (poultry manure), respectively. K loss was also significantly higher under the different fertilizer applications compared to the control treatment by 263 and 343% (inorganic fertilizer), 121 and 202% (pig manure), and 126 and 186% (poultry manure), respectively.

Table 2. Soil nutrient losses (kg ha^{-1} $harvest^{-1}$) due to carrot harvesting

Treatment	OC	N	P	K
		2020		
Control	12.582±1.90b	0.766±0.06b	0.007±0.00b	0.082±0.01c
Inorganic	39.410±4.08a	2.474±0.19a	0.021±0.00a	0.298±0.03a
Pig	36.003±5.13a	1.850±0.26a	0.016±0.00a	0.181±0.02b
Poultry	35.939±4.06a	2.056±0.26a	0.017±0.00a	0.185±0.02b
		2021		
Control	11.545±0.54b	0.670±0.02b	0.004±0.00b	0.059±0.01c
Inorganic	32.770±0.72a	1.978±0.01a	0.020±0.00a	0.261±0.01a
Pig	36.595±0.64a	1.666±0.02a	0.017±0.00a	0.178±0.02b
Poultry	37.360±0.99a	1.829±0.01a	0.018±0.00a	0.169±0.01b

Means are followed by ± standard error. Lower case letters after numerical values indicates significant differences within each column (P< 0.05). Pig, pig manure; Poultry, poultry manure; Inorganic, NPK fertilizer; OC, organic carbon; N, nitrogen; P, phosphorus; K, potassium

Soil Physical and Chemical Properties During Carrot Harvest:

Table 3 shows the soil's physical and chemical properties during the carrot harvest in 2020 and 2021. There was no significant difference in the particle size distribution of the field between the treatments in the two years of study (Table 3). However, a significant difference was observed in the soil's bulk density, gravimetric water content, and organic carbon content under the different treatments (Table 3). On the average, pig manure and poultry manure application resulted in lower soil bulk density compared with the application of inorganic fertilizer and the control (Table 3). Though fertilizer application resulted in significantly higher gravimetric moisture content compared to the control, no significant difference was observed between the fertilizer treatments (Table 3).

Results further showed that pig and poultry manure fertilized plots had higher organic carbon content compared with the inorganic fertilized and control plots in the two years of study (Table 3). More so, the soil's average N, P, and K content during harvesting were higher in all the fertilized plots than in the control. While poultry manure-treated plots had the highest N and P content, the inorganic fertilized plots had the highest K content (Table 3).

Table 3. Soil physical and chemical properties during harvesting of carrot in 2020 and 2021

Treatment	Sand	Silt	Clay	BD ($Mg\ m^{-3}$)	SWC ($g\ g^{-1}$)	OC	N	P ($mg\ kg^{-1}$)	K ($cmol\ kg^{-1}$)
	($g\ kg^{-1}$)					($g\ kg^{-1}$)			
2020									
Control	703.70±5.00a	122.30±8.71a	174.00±12.16a	1.36±0.01a	0.10±0.00b	10.51±0.82c	0.64±0.02d	5.67±0.11c	0.18±0.01b
Inorganic	696.10±9.023a	122.50±8.54a	181.40±14.24a	1.37±0.01a	0.14±0.01a	15.63±0.52b	0.86±0.01c	7.28±0.49b	0.27±0.01a
Pig	694.60±12.14a	122.30±6.22a	183.10±14.89a	1.29±0.01b	0.12±0.00ab	18.80±1.00a	0.96±0.01b	8.12±0.14ab	0.24±0.01a
Poultry	697.40±6.01a	125.00±6.45a	177.60±2.67a	1.26±0.01b	0.13±0.00a	17.93±1.06a	1.02±0.03a	8.41±0.35a	0.24±0.00a
2021									
Control	693.70±6.96a	119.50±9.38a	186.80±15.27a	1.39±0.00a	0.13±0.00b	9.50±1.39c	0.55±0.09d	3.60±0.01c	0.13±0.02c
Inorganic	696.10±9.03a	120.50±8.54a	183.40±14.24a	1.38±0.00a	0.18±0.00a	12.95±2.67b	0.78±0.14c	8.00±0.33b	0.27±0.01a
Pig	694.40±12.00a	122.50±6.30a	183.10±14.89a	1.24±0.01b	0.17±0.00a	19.93±5.78a	0.91±0.24b	9.06±0.17a	0.25±0.01ab
Poultry	697.60±6.01a	125.00±6.45a	177.40±2.70a	1.25±0.02b	0.17±0.00a	19.96±2.59a	0.98±0.11a	9.71±0.27a	0.23±0.01b

Means are followed by ± standard error. Lower case letters after numerical values indicates significant differences within each column ($P < 0.05$). BD, bulk density; SWC, soil water content; OC, organic carbon; N, nitrogen; P, phosphorus; K, potassium; Pig, pig manure; Poultry, poultry manure; Inorganic, NPK fertilizer.

Relationship between Soil Loss, Root Yield, and Soil Physical Properties:

Table 4 shows the relationship between soil loss, fresh root yield, and soil physical properties. A significant ($p < 0.05$) positive linear relationship was observed between soil loss and root yield as well as soil water content (Table 4). Similarly, root yield had a significant ($p<0.05$) positive relationship with soil water content and organic carbon content. In contrast, soil texture, bulk density, and organic carbon showed a poor relationship with soil loss. Another significant relationship was observed between organic carbon, with bulk density and soil water content (Table 4).

Table 4. Pearson correlation coefficients between soil loss parameters, root yield and soil properties

	SLCHspec	SLCHcrop	RY	Sand	Silt	Clay	BD	SWC
SLCHcrop	0.89***							
RY	0.65**	0.83***						
Sand	-0.18	-0.08	0.04					
Silt	0.16	0.05	-0.03	0.18				
Clay	0.08	0.02	0.22	-0.76***	-0.78***			
BD	-0.13	-0.23	-0.11	0.08	0.30	-0.25		
SWC	0.58**	0.65**	0.67**	0.01	-0.27	0.17	-0.26	
OC	0.18	0.23	0.47*	-0.08	-0.20	0.19	-0.80***	0.48*

RY, fresh root yield; BD, bulk density; SWC, soil water content; OC, organic carbon; ***, significant at p = 0.001; **, significant at p = 0.01; *, significant at p = 0.05.

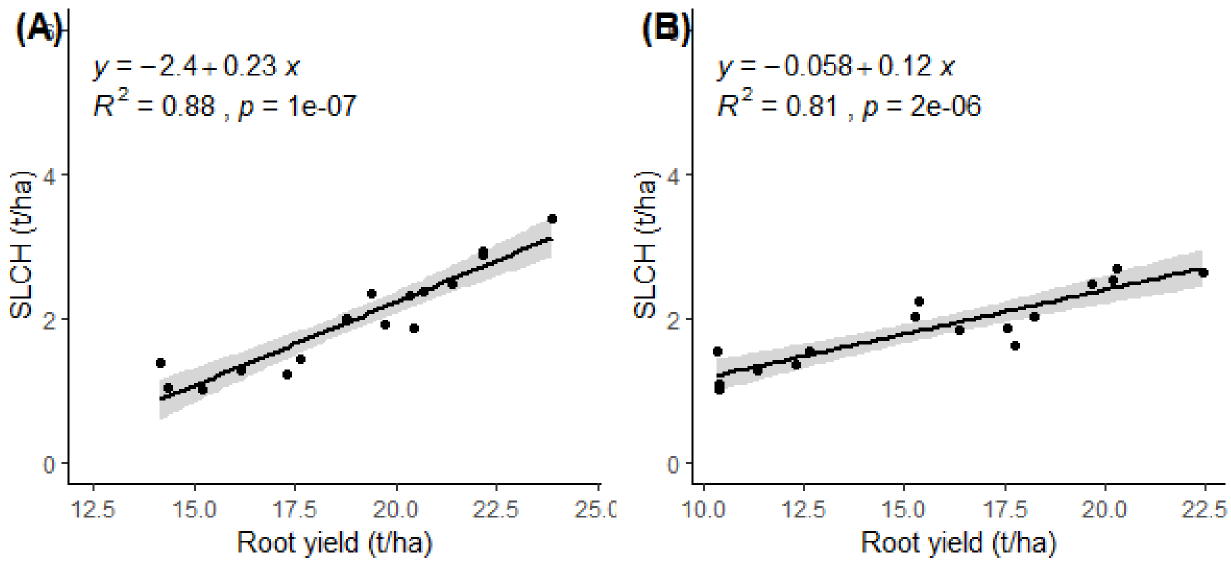

Fig. 6 Relationship between total soil loss and fresh carrot root yield in 2020 (A) and 2021 (B)

DISCUSSION

Fertilizer application increased soil loss due to carrot harvesting. This can be explained by the increase in root yield observed with fertilizer application. Fertilizer application provides the needed nutrients for crop growth and development resulting in increased crop yield. Thus, increase in root size, root number consequently leads to increase in more surfaces to which soil adheres. This can be further explained by the significant positive linear relationship (R^2 = 0.88, 0.81) between soil loss and carrot root yield (Fig. 6). Also, increase in crop yield could result in an increase in soil loss because total soil loss is a product of crop yield. Several researchers have reported crop yield significantly increases soil loss (Isabirye *et al*., 2007; Parlak *et al*., 2016; Oshunsanya *et al*., 2019; Samson and Ityavnongo, 2021 and Oshunsanya *et al*., 2022a). For example, Oshunsanya *et al*. (2019) in a study on soil loss due to yam harvesting, reported fertilizer application increased yam yield and root hair and consequently, soil loss. In this study, the superior root yield associated with the application of inorganic fertilizer and manure is one factor that was responsible for the higher soil loss observed, compared to the control. For instance, the average yield from the inorganic fertilized and manured plots was 1.6 and 1.4 times the yield of the unfertilized plots. A similarly observation was reported by Parlak *et al*. (2016) on soil loss due to mechanically and manually harvested carrot, they attributed crop yield as a factor influencing soil loss. Our finding is in agreement with the works of Ruysschaert *et al*. (2004) which postulates that practices that increase crop yield could potentially increase soil loss.

In addition to crop yield, soil water content at harvesting is another factor that may have been responsible for the higher soil loss associated with fertilizer application. In this study, the water content of the fertilized plots was significantly higher than the control, and this may increase the adherence of soil particles to the harvested roots. This can be explained by the significant positive relationship between soil loss and soil water content. Furthermore, it could be inferred from the positive relationship between soil water content and crop yield that soil water content could indirectly influence soil loss. Many researchers have reported soil moisture content at the time of harvest to be a major controlling factor of soil loss from crop harvesting (Ruysschaert *et al*., 2004; Ruysschaert *et al*., 2007b; Sumithra *et al*., 2013; Mwango *et al*., 2015; Parlak *et al*., 2021 and Oshunsanya *et al*., 2022a). For instance, Oshunsanya *et al*. (2022b) reported moisture content to have a positive relationship with soil loss due to crop harvesting. In another experiment, Oshunsanya *et al*. (2022a) reported soil moisture content at the time of harvest as a significant factor responsible for the difference in soil loss between peanut and cassava. The increased soil moisture content of the fertilized plots may have resulted from the higher vegetative growth of carrot, which could help provide soil cover, thus reducing water evaporation from the surface. Agbede (2021) observed that the application of fertilizer and soil amendment resulted in better carrot vegetative growth and overall productivity.

Other studies have reported soil properties such as bulk density, soil structure, and texture to be critical factors controlling soil loss (Ruysschaert *et al*., 2007b; Dada *et al*., 2016; Oshunsanya *et al*., 2018; Parlak *et al*., 2021 and Samson and Ityavnongo, 2021). For example, Oshunsanya *et al*. (2018) reported soil bulk density negatively related to soil loss due to yam harvesting. Dada *et al*. (2016) also observed that soil bulk density in addition to soil texture has significant effects on soil loss. Similarly, Samson and Ityavnongo (2021) in an experiment, reported a significant relationship between soil texture and soil loss due to yam harvesting. However, in our study, soil properties such as bulk density and soil texture had no relationship with soil loss. This could result from the uni form variation in soil texture in the experimental plots study area. Though the application of manure in this study lowered the soil bulk density, it had no significant effect on soil loss. In addition, soil organic carbon had no direct relationship with soil loss but the significant positive relationship between soil water content and organic carbon could indicate an indirect relationship, thus suggesting that increased organic carbon content could affect other soil properties that directly relate to soil loss. Moreover, continuous fertilizer and manure application over a long period may affect these soil properties, consequently influencing soil loss. Oshunsanya *et al*. (2019) reported enhanced adherence of soil particles to yam due to significant interaction between clay and organic matter owing to the continuous addition of organic fertilizers.

A major consequence of soil loss due to crop harvesting is the associated nutrient loss. As expected, fertilizer application significantly increased soil nutrient loss for OC, N, P, and K. Variation in soil nutrient loss is attributed to the differences in soil nutrient concentration resulting from the added nutrients from the fertilizers. Soil inherent nutrient concentration is a significant factor that influences nutrient loss (Mwango *et al*., 2015; Yu *et al*., 2016 and Faraji *et al*., 2017). Therefore, higher nutrient content would likely correspond to a higher amount of nutrient loss. The application of fertilizer increased the soil primary nutrients, thus, in combination with the higher soil loss resulted in high soil nutrient loss compared with the control. Also, adding manure could help improve the soil's organic matter, thereby improving the retention of nutrients in the soil and consequently allowing more nutrients to be removed with accompanying soil loss. This could be responsible for the high soil nutrient loss in manured plots. Another likely reason for the higher soil nutrient loss noticed with fertilization is the higher carrot root yield. Previous research has shown root yield to be a contributing factor to soil nutrient loss (Isabirye *et al*., 2007; Oshunsanya, 2016a; Oshunsanya, 2016b; Parlak *et al*., 2018 and Samson and Ityavnongo, 2021). Higher root yield could provide a larger root size area for soil adherence which will also account for the increased nutrient loss (Oshunsanya *et al*., 2019). Average soil nutrient loss due to fertilizer application in this study was 1.97 kg N ha^{-1} $harvest^{-1}$, 0.05 kg P ha^{-1} $harvest^{-1}$, 0.21 kg K ha^{-1} $harvest^{-1}$ and was higher than the nutrient loss of 0.04 kg N ha^{-1} $harvest^{-1}$, 0.03 kg P ha^{-1} $harvest^{-1}$, 0.01 kg K ha^{-1} $harvest^{-1}$, and 1.84 kg N ha^{-1} $harvest^{-1}$, 0.02 kg P ha^{-1} $harvest^{-1}$ reported for unfertilized sweet potato and sugar beets (Oshunsanya, 2016b and Parlak et al., 2021). However, soil nutrient loss in this study was lower than nutrient losses of 31.00 kg N ha^{-1} $harvest^{-1}$, 0.08 kg P ha^{-1} $harvest^{-1}$, and 1.25 kg K ha^{-1} $harvest^{-1}$ reported for carrot (Mwango *et al*., 2015). This difference could result from differences in the quantity of soil loss, crop yield, and soil properties. For example, their study reported a soil loss of 7.10 t $ha^{-1,}$ which is about 3.68 times the average soil loss (1.93 t ha^{-1}), from our study. Fertilizer application is therefore encouraged not just for yield increase alone but to replenish the removed nutrients.

The amount of soil loss shown in this study, justifies the need for soil loss as a result of crop harvesting to be considered an agent of soil degradation, in addition to water erosion. Moreover, continuous soil removal could lead to topsoil depletion, which is a carbon sink, thus reducing the soil's carbon sequestration potential (Oshunsanya *et al*., 2022a). Although fertilizer application increases soil loss due to crop harvesting, our study does not discourage the use of fertilizer, but encourages that carrot roots should be cleaned thoroughly during harvesting on the field to reduce and mitigate soil loss from the farm. In addition, identifying optimal soil water content before harvesting can be an effective strategy for reducing soil loss (Parlak *et al*., 2021). Furthermore, though the impact of soil nutrient loss on soil fertility could be cushioned by fertilizer application, its environmental implication must not be underrated. This is because continuous removal and deposition of soil nutrients into water bodies could cause contamination and pollution, thus creating an unfavorable environment for aquatic organisms. Yu *et al*. (2016) in a study on soil loss due to potato and sweet potato harvesting, reported that about 92.4% of soil loss is directly discharged into water bodies, thus contributing to between 3 and 20% of the total N and P loads in water bodie s.

CONCLUSION

Fertilizer application increases soil loss due to crop harvesting. Higher carrot yield associated with fertilizer application was a major determining factor affecting soil loss. In addition, soil moisture content at harvesting was essential in influencing soil loss. Also, fertilizer application resulted in higher soil nutrient loss. Similarly, crop yield and soil nutrient concentration were critical drivers of soil nutrient loss. Among the fertilizer types used, inorganic fertilizer produced the highest root yield and, consequently, higher soil loss compared to pig and poultry manure.

Results showed that soil loss due to carrot harvesting contributes to soil degradation. Hence, soil conservation practices such as cleaning carrot roots during harvesting should be adopted, especially when fertilizer is used in the growing cycle. Also, fertilizer application should be done to replenish nutrient loss to cushion fertility decline. In addition, long-term field trials are needed to better understand the dynamics of soil loss due to carrot harvesting under various fertilization strategies.

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Conflict of Interests
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REFERENCE

Agada, B., Obi, M., & Ali, A. (2016). Rainfall Characteristics at Makurdi, North–Central Nigeria II. *AFRREV STECH: An International Journal of Science and Technology, 5*, 40–46. https://doi.org/10.4314/stech.v5i1.4

Agbede, T. M. (2021). Effect of tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their mixture on soil properties, growth and carrot (*Daucus carota* L.) yield under tropical conditions. *Heliyon, 7*, e07391. https://doi.org/10.1016/j.heliyon.2021.e07391

Ahmad, Z., Ali, N., Ahmad, M., Haq, S., & Ahmad, S. (2005). Yield and economics of carrot production in organic farming. *Sarhad Journal of Agriculture, 21*(3), 357–364.

Ahmed, A., Sambo, B. E., Arunah, U. L., & Odion, E. C. (2014). Response of farmyard manure and inorganic fertilizers for sustainable growth of carrot (*Daucus carota* L.) in Northern Nigeria. *Journal of Agriculture and Veterinary Science, 7*(2), 18-25. https://doi.org/10.9790/2380-07221825

Arscott, S. A., & Tanumihardjo, S. A. (2010). Carrots of many colors provide basic nutrition and bioavailable phytochemicals acting as a functional food. *Comprehensive Reviews in Food Science and Food Safety, 9*(2), 223–239. https://doi.org/10.1111/j.1541-4337.2009.00103.x

Bose, T. K., & Som, M. G. (1990). Vegetable Crops in India 1:120-135.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen-Total. In *Methods of Soil Analysis, Part 2 Chemical and Microbiological Properties*, 2nd edition, ed. A.L. Page, P.H. Miller, and D.R. Keeney, 539-579. Madison, WI: *American Society of Agronomy.*

Dada, P. O. O., Adeyanju, O. R., Adeosun, O. J., & Adewumi, J. K. (2016). Effects of soil physical properties on soil loss due to manual yam harvesting under a sandy loam environment. *International Soil and Water Conservation Research, 4*(2), 121–125. https://doi.org/10.1016/j.iswcr.2016.02.007

Food and Agricultural Organization (FAO). (2022). Food and Agricultural Organization Bulletin. Website: fao.org/global-soil-partnership. *Date Assessed:* 22 July 2022.

Faraji, M., Chakan, A. A., Jafarizadeh, M., & Behbahani, A. M. (2017). Soil and nutrient losses due to root crops harvesting: a case study from southwestern Iran. *Archives of Agronomy and Soil Science, 63*(11), 1523–1534. https://doi.org/10.1080/03650340.2017.1296133

Gee, G. W., & Or, D. (2002). Particle size analysis. *Methods of Soil Analysis. Part 4. Physical methods* (eds. Dane JH, Topp GC), SSSA, Book Series No: 5, Madison, pp 255–293. https://doi.org/10.2136/sssabookser5.4.c12

Grossman, R. B., & Reinsch, T. G. (2002). Bulk density and linear extensibility. *Methods of Soil Analysis. Part 4. Physical Methods* (eds. Dane JH, Topp GC), SSSA, Book Series No: 5, Madison, pp 201–228. https://doi.org/10.2136/sssabookser5.4.c9

Haynes, R. J., & Naidu, R. (1998). Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutrient Cycling in Agroecosystems, 51*(2), 123-137.

Isabirye, M., Ruysschaert, G., Van Linden, L., Poesen, J., Magunda, M. K., & Deckers, J. (2007). Soil losses due to cassava and sweet potato harvesting: A case study from low input traditional agriculture. *Soil and Tillage Research, 92*(1–2), 96–103. https://doi.org/10.1016/j.still.2006.01.013

Mclean, E. O. (1982). Soil pH and lime requirements. In: Page et al. (Eds.), *Methods of Soil Analysis, Part 2, Chemical and microbial properties*, 2nd ed. Agronomy monograph 9, ASA, SSSA, Madison, WI, pp.199-224.

Mwango, S., Msanya, B., Mtakwa, P., Kimaro, D., Deckers, J., Poesen, J., … Sanga, R. (2015). Soil Loss due to Crop Harvesting in Usambara Mountains, Tanzania: The Case of Carrot, Onion and Potato. *International Journal of Plant and Soil Science, 4*(1), 18–28. https://doi.org/10.9734/ijpss/2015/12479

Nelson, D. W., & Sommers, L. W. (1982). Total carbon, organic carbon, organic matter. In: Page et al. (Eds.), *Methods of Soil Analysis, Part 2, Agronomy Monograph 9, Soil Science Society of America* pp.539-579.

Olsen, S. R., & Sommers, L. E. (1982). Phosphorus. In *Methods of Soil Analysis, Part 2 Chemical and Microbiological Properties*, ed. A.L. pp 403-430. Madison, WI: American Society of Agronomy, *Soil Science Society of America.*

Oshunsanya, O., Samson, V. M., & Yu, H. (2022a). Soil loss due to harvesting of peanut and cassava under traditional farming systems: Cost implications of soil nutrient loss. *Journal of Soil and Water Conservation, 77*(3), 240-248. https://doi.org/10.2489/jswc.2022.00111

Oshunsanya, S., Yu, H., Onunka, C., Samson, V., Odebode, A., Sebiotimo, S. & Xue, T. (2022b). Yam Staking Reduces Soil Loss Due to Crop Harvesting under Agronomic Management System: Environmental Effect of Soil Carbon Loss. *Agronomy, 12*(12). doi:10.3390/agronomy12123024

Oshunsanya, S. O. (2016a). Quantification of soil loss due to white cocoyam (*Colocasia esculentus*) and red cocoyam (*Xanthosoma sagittifolium*) harvesting in traditional farming system. *Catena, 137*, 134–143. https://doi.org/10.1016/j.catena.2015.09.013

Oshunsanya, S. O. (2016b). Alternative method of reducing soil loss due to harvesting of sweet potato: A case study of low input agriculture in Nigeria. *Soil and Tillage Research, 158*, 49–56. https://doi.org/10.1016/j.still.2015.11.007

Oshunsanya, S. O., Yu, H., & Li, Y. (2018). Soil loss due to root crop harvesting increases with tillage operations. *Soil and Tillage Research, 181*, 93–101. https://doi.org/10.1016/j.still.2018.04.003

Oshunsanya, S. O., Yu, H., Li, Y., & Saggar, S. (2019). Root hairs and cortex contribute to soil loss due to root crop harvesting. *Catena, 174*, 514–523. https://doi.org/10.1016/j.catena.2018.11.016

Panagos, P., Borrelli, P., & Poesen, J. (2019). Soil loss due to crop harvesting in the European Union: A first estimation of an underrated geomorphic process. *The Science of the Total Environment, 664*, 487-498. https://doi.org/10.1016/j.agee.2004.12.005

Pant, B., & Manandhar, S. (2007). In vitro propagation of carrot (*Daucus carota* L.) *Scientific World, 5*(5), 51–53.

Parlak, M., & Blanco-Canqui, H. (2015). Soil losses due to potato harvesting: A case study in western Turkey. *Soil Use and Management, 31*(4), 525–527. https://doi.org/10.1111/sum.12225

Parlak, M., Çiçek, G., & Blanco-Canqui, H. (2018). Celery harvesting causes losses of soil: A case study in Turkey. *Soil and Tillage Research, 180*, 204–209. https://doi.org/10.1016/j.still.2018.03.011

Parlak, M., Everest, T., & Blanco-Canqui, H. (2021). Soil Loss due to Sugar Beet Harvesting in Northwestern Turkey. *Journal of Soil Science and Plant Nutrition, 21*(4), 2993–3001. https://doi.org/10.1007/s42729-021-00584-z Parlak, M., Palta, Ç., Yokuş, S., Blanco-Canqui, H., & Çarkaci, D. A. (2016). Soil losses due to carrot harvesting in south central Turkey. *Catena, 140*, 24–30. https://doi.org/10.1016/j.catena.2016.01.012

R Studio Team. (2022). Integrated development environment for R. Studio PBC, Boston, MA. http: www.rstudio.com

Rhodes, J. D. (1982). Cation exchange capacity. In A.L. Page (Ed.), *Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties*, 2nd Ed. American Society of Agronomy, Madison, Wisconsin, pp. 149-157.

Ruysschaert, G., Poesen, J., Verstraeten, G., & Govers, G. (2004). Soil loss due to crop harvesting: Significance and determining factors. *Progress in Physical Geography, 28*(4), 467–4501. https://doi.org/10.1191/0309133304pp421oa

Ruysschaert, G., Poesen, J., Verstraeten, G., & Govers, G. (2006a). Soil losses due to mechanized potato harvesting. *Soil and Tillage Research, 86*(1), 52–72. https://doi.org/10.1016/j.still.2005.02.016

Ruysschaert, G., Poesen, J., Verstraeten, G., & Govers, G. (2006b). Soil Losses due to Crop Harvesting in Europe. In *Soil Erosion in Europe* (pp. 609–621). John Wiley and Sons Ltd. https://doi.org/10.1002/0470859202.ch44

Ruysschaert, G., Poesen, J., Verstraeten, G., & Govers, G. (2007a). Soil loss due to harvesting of various crop types in contrasting agro-ecological environments. *Agriculture, Ecosystems and Environment, 120*(2–4), 153–165. https://doi.org/10.1016/j.agee.2006.08.012

Ruysschaert, G., Poesen, J., Wauters, A., Govers, G., & Verstraeten, G. (2007b). Factors controlling soil loss during sugar beet harvesting at the field plot scale in Belgium. *European Journal of Soil Science, 58*(6), 1400–1409. https://doi.org/10.1111/j.1365-2389.2007.00945.x

Samson, V. M., & Ityavnongo, K. M. (2021). Quantification of soil and nutrient loss due to yam harvesting: A case study in two local government areas in Benue state, Nigeria. *Nigerian Journal of Soil Science, 33*(3), 42–47. https://doi.org/10.36265/njss.2021.310306

Sharma, K. D., Karki, S., Thakur, N. S., & Attri, S. (2012). Chemical composition, functional properties and processing of carrot - a review. *Journal of Food Science and Technology, 49*, 22–32. https://doi.org/10.1007/s13197-011-0310-7

Sumithra, R., Thushyanthy, M., & Srivaratharasan, T. (2013). Assessment of soil loss and nutrient depletion due to cassava harvesting: A case study from low input traditional agriculture. *International Soil and Water Conservation Research, 1*(2), 72–79. https://doi.org/10.1016/S2095-6339(15)30041-1

Tuĝrul, K. M., Içöz, E., & Perendeci, N. A. (2012). Determination of soil loss by sugar beet harvesting. *Soil and Tillage Research, 123*, 71–77. https://doi.org/10.1016/j.still.2012.03.012

Yu, H., Li, Y., Zhou, N., Chappell, A., Li, X., & Poesen, J. (2016). Soil nutrient loss due to tuber crop harvesting and its environmental impact in the North China Plain. *Journal of Integrative Agriculture, 15*(7), 1612–1624. https://doi.org/10.1016/S2095-3119(15)61268-0