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Impacts of soil conservation techniques on soil erodibility on an Alfisol

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A R T I C L E I N F O

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A B S T R A C T

Soil erosion is a serious challenge for sustainable crop production. Alfisols in Nigeria are easily prone to soil degradations which have significantly reduced soil productivity, crop yield and increased cost of production. The use of soil conservation measures are vital interventions for sustainable crop production against the effects of erosion. The impacts of soil conservation on erodibility of an Alfisol was investigated in a tropical alfisol in Southwestern Nigeria. The study utilized four-soil conservation measures - *Irvingia wombulu*, *Irvingia garbonensis*, paddock and *Cynodon plectostachyus* was established on 20.4 ha land for 25 years, and replicated thrice based on land area. Empirical soil erodibility factor using Universal Soil Loss Equation (USLE) and Water Erosion Prediction Project (WEPP) erodibility factor models was determined. Analysis of variance analysis was done using R statistics to ascertain response patterns of the soil conservation measures to erodibility. Correlation was conducted for the conformity and relationship between erodibility models and soil properties. *I. garbonensis* soil conservation measure gave the least erodibility factor ($K = 0.07$), among paddock ($K = 0.09$), *I. wombulu* ($K = 0.11$) and *C. plectostachyus* with the highest erodibility factor ($K = 0.17$), indicating that *I. garbonensis* has the highest potential for soil conservation. Soil conservation measures significantly ($p \leq 0.05$) influenced soil properties. Wischmeier and Mannering's USLE erodibility and WEPP's rill and inter-rill erodibility were not significantly ($p \geq 0.05$) different across the soil conservation measures. Elswaify and Dangler's USLE erodibility correlated best with Wischmeier and Mannering USLE erodibility ($r = 1.00$) and WEPP's rill ($r = 0.8$) and inter-rill ($r = 0.8$) erodibility. Sand, silt, organic carbon, available phosphorus and aggregate stability significantly ($p \leq 0.05$) correlated with USLE erodibility factor. Elswaify and Dangler USLE erodibility gave higher precision in erodibility determination of the soils. *I. garbonensis* was more efficient in reducing soil erosion, indicating that it is the best soil conservation measure for sustainable agriculture in alfisols in the tropics.

1. Introduction

Increase in world population and corresponding decline in arable land pose a great challenge to present day agriculture. This is

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because the decrease in agricultural production have seldom met the demand for food supply for the ever - increasing population especially in sub-Sahara Africa. Bhat et al. [1] reported that these changes have led to intensification of agriculture resulting into conversion of natural vegetation areas to cropping land. Climatic factors in combination with the sustained overexploitation of land resources have led to the loss of the top fertile layer of soils. Soil erosion is a sacrosanct pandemic that greatly affected land and soil quality in the tropics. Soil erosion is the washing away of the top soil by agents of denudation (such as rain, glacier ice, wind etc.). Oshunsanya and Nwosu [2] noted that soil erosion is the major cause of land degradation in most regions of the world. The rate of soil erosion over a land surface is dependent on several factors including erosive force of rainfall and the resistance of the soil to erode.

Nwosu and Okon [3] reported that about 80% of land degradation in Nigeria is due to soil erosion which had greatly affected environmental sustainability and crop yield to meet the demand of the high population in the country. Oshunsanya and Nwosu [4] noted that soil erodibility establishes the ease at which a given soil is prone to erosion. Erodibility has become a key parameter that assists policy makers, farmers and researchers on the true need for soil conservation against the menace of soil erosion. Erodibility is the quantity of soil loss per unit exogenic force such as rainfall, surface flow, and seepage [2]. Wang et al. [5] regards soil erodibility as a vital tool that evaluates the soil susceptibility to erosion. O'Geen and Schwankl [6] earlier maintained that the resistance of the soil to erosion is inversely proportional to the erodibility factor (K).

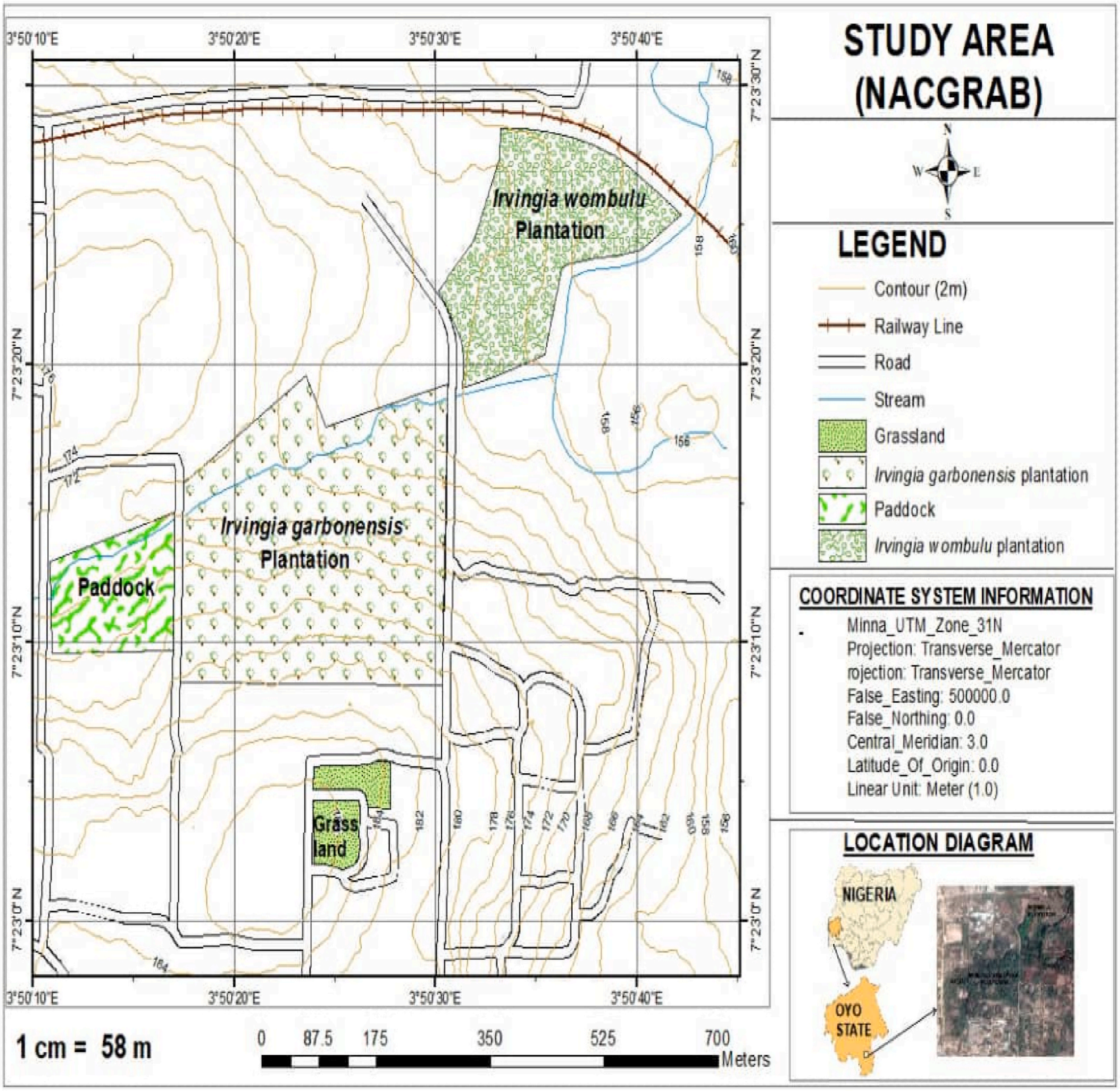

Fig. 1. Map of study area showing conservation measures.

Soil conservation entails the various soil management techniques geared at sustaining, preventing and improving soil quality conditions for sustainable crop production and land productivity. Diverse soil conservation techniques, which range from mulching, fallowing, use of vetiver grass technology, agro-forestry systems aimed at fostering an increased soil productivity conditions and reducing the effects of soil erosion, have been practiced in different regions of the world. There is pertinence for comprehensive soil conservation programmes in erosion susceptible areas, in order to protect the land from catastrophic degradation.

Soil erosion in sub-Sahara Africa has resulted in an average annual harvest yield reduction of 8.2% and if soil erosion rates remains unabated, the average food production will decrease in the future [1,7]. Despite the great high soil loss and runoffs reported in southwestern Nigeria [2,4,8], soil conservation programmes are not readily available in the areas within southwestern and central eastern Nigeria [9–11]. Soil conservation is dependent on understanding the complex relationship between land, land use, the farmer and the socio-economic-political environment [12]. Bhat et al. [1] maintained that on the global scale, the period of the earliest significant change in land use corresponds to a first wave of the soil erosion. The areas with human intervention have high rate of soil erosion of 2.92 t ha^{-1} $year^{-1}$. In order to strike a balance between agricultural output and conservation, soil erosion control becomes a very essential component. Bukari [13] observed that the farmers who successfully applied the use of soil conservation methods have improved their production levels territorially and the standard of life of their families.

Several soil conservation techniques have been developed in the past to tackle soil erosion problems. In sub-Sahara Africa, farmers often resort to the use of agronomic measures of soil erosion management due to its cheap, durable and very effective attributes in erosion control [1]. However, there is little information on the relationship between the sustained use soil conservation techniques with erodibility of an Alfisol. This paper therefore seeks to establish the effects of soil conservation on soil erodibility and soil physical and chemical indicators for better erosion management and agricultural production respectively.

2. Materials and methods

2.1. Site description and soil sampling

The study was conducted at the National Centre for Genetic Resources and Biotechnology (NACGRAB) in Ido Local Government Area of Oyo State in Southwestern Nigeria (Fig. 1). The area is defined between latitudes 3°50″10′E and longitudes 7°23″10′N with a total land area of 20.4 ha. The area has a mean annual rainfall between 1200 and 1800 mm with about 8 months of rain. The mean annual minimum and maximum temperature are 24 °C and 33 °C respectively. The area is characterized by the derived savanna vegetation. Four sections were considered for this study; each section consisting of a soil conservation measure replicated based on the land area. The sections were - *Irvingia garbonensis* Plantation (comprising of sixty accessions with six replicates), *Irvingia wombulu* plantation (comprising of five accessions, replicated twenty times), Animal Genetic Resources (Paddock) and *Cynodon plectostachyus* (Grassland) unit. These units represent the soil conservation measures. Soil samples were made at 0–30 cm depth using soil auger in three replicates in a randomized complete block design (RCBD). The number of soil samples obtained from each soil conservation method was based on the land area (Table 1). The samples collected was appropriately labeled and bagged to avoid contamination of soil samples collected. Soil samples were analyzed for routine soil physical and chemical properties.

Particle size distribution was determined using the Bouyoucos hydrometer method [14] and soil texture was evaluated using the USDA soil textural class ratings. Bulk density was determined using core method [15]. Available water capacity was determined using the method as reported by Ref. [16]. The soil pH was determined with the pH meter using glass electrode in a 1:1 soil to water ratio [16].

Total nitrogen (T.N) was determined by Kjehdahl digestion method [17]. Organic carbon was determined using the Walkey Black wet oxidation method [18]. Organic matter (O.M) was calculated by using the van Bemmelen's correction factor of 1.724. Available phosphorus (Avail. P) was determined with the aid of a spectrophotometer [16]. Exchangeable bases were determined using neutral $NHOAC_4$ leachate. Exchangeable Ca and Mg were determined by EDTA versanate titration method [19]. Exchangeable Na and K were determined by the flame photometer method. Exchangeable acidity (E.A) was determined by leaching the soil with 1 N KCl and titrating with 0.05 N NaOH [19].

2.2. Determination of soil erodibility factor (K)

Several equations have been devised for modelling soil erosion in various parts of the tropics [20,21]. However, the soil erodibility for each soil type was evaluated using Universal Soil Loss Erodibility (USLE) and Water Erosion Prediction Project (WEPP) models as

Table 1
Soil sample size of soil conservation measures at study area.

Soil conservation method	Land area (ha)	Number of soil samples
Irvingia garbonensis	8.4	126
Irvingia wombulu	5.6	84
Paddock	3.4	51
Cynodon plectostachyus	3.0	45
Total	**20.4**	**306**

*ha = hectares.

outlined by Ref. [5]. These two erodibility models were employed because their precision of prediction is dependent on the soil types. The Universal Soil Loss Equation (USLE) predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. The USLE was used for this study because it is not site specific and as such its applicability is not limited to any region or location, hence making it widely adopted for soil erodibility modelling. The USDA added that the USLE model is the most significant development in soil and water conservation in the 20th century owing to its efficiency and wide adoptability. In addition [22], and [[2] studied the use of USLE to predict soil erodibility in Southwestern Nigeria, and observed high efficiency with the devised models from soil properties for four tropical soil types in the Nigeria.

The two USLE models employed in this study to estimate the USLE soil erodibility factor K include:

(i) El-Swaify and Dangler [23]

$$K = -0.03970 + 0.00311X_2 + 0.00043\ M + 2\ 0.00185X_3 + 0.00258X_4 - 0.00823X_5 \tag{1}$$

Where; X_2 is the proportion of unstable aggregates >0.25 mm (%); X_3 is the soil water content; X_4 is the redefined silt (%) = %silt + % fine sand; and X_5 is the redefined sand fraction (0.01–2 mm).

Although this model was originally developed from volcanic materials, studies have found them also suitable for estimating soil erodibility for tropical soils owing to their similarities of model variables which are used on alfisols in the tropics. Oshunsanya and Nwosu [2] have observed the applicability of the model in tropical soil erodibility modelling.

(ii) Wischmeier and Mannering [24]

$$K = (0.043\ R + 0.62/OM + 0.0082\ S – 0.0062C)\ \%silt \tag{2}$$

Where R (soil reaction) is directly proportion to soil pH, OM is organic matter, S is percent sand (%sand), and C is the clay ratio.

$$\text{Clay ratio} = \frac{\%\ \text{sand} + \%\ \text{silt}}{\%\ \text{clay}} \tag{3}$$

The WEPP model was employed in estimating soil erodibility K. Both inter-rill and rill erodibility WEPP models were used as reported by Wang et al. (2013). For soils having more than 30% sand, equations (4) and (5) were used to estimate soil erodibility K

$$K_{ib} = 2.728 \times 10^6 + 1.921 \times 10^7 fs \tag{4}$$

$$K_{rb} = 0.00197 + 0.030\text{fs} + 0.03863e^{-1840M} \tag{5}$$

Where K_{ib} is inter rill erodibility, K_{rb} is rill erodibility, fs are fine sand (%) and M is organic matter (%).

2.3. Soil erodibility rating

The erodibility rating as modified by Oshunsanya and Nwosu [4] will be used to rate the soil erodibility of the soil conservation plots. Table 2 summarizes the soil erodibility ratings for soils in the tropics.

2.4. Empirical deduction

2.4.1. Silt:clay ratio

This is an index for soil erodibility. It denotes the ration of silt to clay in the soil expressed as a percentage. This index is particularly very important in tropical regions for soil erodibility modelling as [2,4] observed that there was a strong significant relationship between the ration of silt t clay to the ease of erosion in four common soil types in Nigeria.

$$\text{Slit:clay} = \frac{\%\ \text{silt}}{\%\ \text{clay}} \tag{6}$$

Table 2
Physical Properties (0–30 cm) as influenced by conservation methods.

Soil Conservation Strategy	Sand	Silt	Clay	Texture	BD (Mg/m^3)	TP (%)
	g/kg					
Irvingia wombulu	838.7 ± 45.1	117.7 ± 34.6	43.7 ± 23.8	LS	1.46 ± 0.01	45.2 ± 0.8
Irvingia garbonensis	780.0 ± 33.3	159.7 ± 43.7	60.3 ± 12.3	LS	1.55 ± 0.13	41.0 ± 4.2
Paddock	760.0 ± 48.9	180.0 ± 40.0	60.0 ± 28.6	LS	1.58 ± 0.11	40.2 ± 4.1
Cynodon plectostachyus	842.0 ± 47.1	108.0 ± 34.8	50.0 ± 25.3	LS	1.47 ± 0.02	44.9 ± 0.5
LSD	24.9	38.7	NS		NS	NS

NB: LS = Loamy Sand; BD = Bulk Density; AWC = Available Water Capacity; TP = Total Porosity; Means with the same letters in each column, are not significantly different at 5%; NS = Not significant.

2.5. Data analysis

All data obtained were subjected to analysis of variance (ANOVA) using R Script statistical software to ascertain the response patterns of the soil conservation measures to soil physical, chemical and erodibility properties. LSD was used to establish significant difference between the means. Also, data imported to Origin Pro. Software version 8.1 from the study was analyzed for correlation between selected soil properties and standard USLE and WEPP erodibility models were made to establish the relationship among the soil conservation measures.

3. Results

3.1. Soil properties as influenced by soil conservation methods

The soil physical properties of the four soil conservation methods – *Irvingia wombulu, Irvingia garbonensis*, paddock and *Cynodon plectostachyus* was presented in Table 2. Texturally, all the soils from the four soil conservation measure were loamy sand. Bulk density did not vary significant ($p \leq 0.05$) among the soil conservation measures, however, paddock had the highest bulk density (BD) with 1.58 Mg m^{-3}, followed by *Irvingia garbonensis* (1.55 Mg m^{-3}), *Cynodon plectostachyus* (1.47 Mg m^{-3}) and least in *Irvingia wombulu* with 1.46 Mg m^{-3}. Similarly, *Irvingia wombulu* had the highest total porosity of 45.2%, while paddock had the least total porosity with 40.2%.

The soil chemical properties used for the study were presented in Table 3. Soil pH, total nitrogen and exchangeable acidity were not significantly ($p \leq 0.05$) different among the soil conservation measures. However, soil organic carbon (SOC), available phosphorus, exchangeable calcium, magnesium and potassium were significantly different among the soil conservation measures. Paddock had the highest SOC with 20.6 g kg^{-1} while grassland (13.2 g kg^{-1}) had the least SOC. *Irvingia garbonensis* had the highest available phosphorus content with 18.8 mg kg^{-1} while grassland had the least with 8.7 mg kg^{-1}. Also, *Irvingia wombulu* had the highest exchangeable bases – Ca (6.05 cmol kg^{-1}), Mg (2.80 cmol kg^{-1}) and K (0.58 cmol kg^{-1}) content of the soil conservation measures, while paddock has the least exchangeable base - Ca (2.96 cmol kg^{-1}), Mg (0.77 cmol kg^{-1}) and K (0.22 cmol kg^{-1}).

3.2. Soil erodibility as influenced by soil conservation measures

Soil erodibility indices of the soils of the conservation measures at the depth of 0–30 cm is presented in Table 4. Paddock had the highest silt:clay ratio (3.0) while *Cynodon plectostachyus* has the least silt:clay ratio (2.2). *Irvingia wombulu* had the highest clay ratio of 21.9 while *Irvingia garbonensis* has the least with 15.6. Stable and unstable aggregates, as well as the soil organic matter were significantly different among the soil conservation measures, however, there was no significant difference in the silt:clay and clay ratio among the soil conservation measures studied. *Irvingia garbonensis* had the most stable aggregates (22%) while *Cynodon plectostachyus* had the least stable aggregates (15.8%). In a similar way, *Cynodon plectostachyus* had the most unstable aggregates (84.2%) while Irvingia garbonensis had the least unstable aggregates (78.0%). Also, Paddock had the highest soil organic matter content with 35.4 g kg^{-1} while *Cynodon plectostachyus* has the least with 22.7 g kg^{-1}.

Furthermore, the soil erodibility factor (K) of the soil conservation measures was presented in Table 5. Elswaify and Dangler's USLE erodibility was significantly different ($p \leq 0.05$) among the soil conservation measures. There was no significant difference in the soil erodibility factor as devised by Wischmeier and Mannering (USLE) and the WEPP inter-rill and rill erodibility respectively. *Irvingia garbonensis* had the least erodibility factors for both USLE (0.07 for Elswaify and Dangler and 0.95 for Wischmeier and Mannering) and WEPP (2.62 for inter-rill and 0.30 form rill) erodibility while *Cynodon plectostachyus* had the highest USLE (0.17 for Elswaify and Dangler and 1.37 for Wischmeier and Mannering) and WEPP (3.13 for inter-rill and 0.45 for rill) erodibility factors. Also, *Irvingia garbonensis* and paddock had a very low erodibility risk (K1) while *Irvingia wombulu* and *Cynodon plectostachyus* had a low erodibility risk (K5) under USLE soil erodibility rating. Similarly, using WEPP erodibility model, *Irvingia garbonensis* had a moderate erodibility risk (K3) while *Irvingia wombulu* and *Cynodon plectostachyus* had a high erodibility risk (K5) (Table 6).

Table 3
Chemical properties (0–30 cm) as influenced by conservation methods.

Soil Conservation Strategy	pH (H2O)	OC	T.N	Avail P.	EA	Ca	Mg	K
		g kg-1		mg kg-1		cmol kg-1		
I. wombulu	6.3 ± 0.22	18.2 ± 2.5	1.92 ± 0.28	18.8 ± 1.2	0.37 ± 0.1	6.05 ± 0.7	2.80 ± 0.7	0.58a±0.03
I. garbonensis	6.2 ± 0.23	18.6 ± 0.7	1.99 ± 0.08	19.0 ± 0.7	0.34 ± 0.1	3.86 ± 0.5	1.37 ± 0.1	0.25b ± 0.09
Paddock	6.0 ± 0.18	20.6 ± 3.3	2.13 ± 0.28	9.9 ± 0.7	0.30 ± 0.1	2.96 ± 0.7	0.77 ± 0.2	0.22c±0.12
C. plectostachyus	6.1 ± 0.17	13.2 ± 0.9	1.22 ± 0.27	8.7 ± 1.1	0.29 ± 0.1	4.58 ± 0.6	2.19 ± 0.1	0.17d ± 0.05
LSD	NS	2.9	NS	3.4	NS	2.2	1.12	0.11

NB: OC = organic carbon; TN = Total Nitrogen; Avail. P = Available Phosphorus; EA = Exchangeable Acidity; Means with the same letters in each column, are not significantly different at 5%; NS = Not Significant.

Table 4
Soil erodibiity indicies as influenced by the soil conservation measures at 0–30 cm soil depth.

Soil Conservation Strategy	Silt: Clay	Clay ratio	Stable Aggregate (%)	Unstable Aggregate (%)	OM (g kg^{-1})
I.wombulu	2.7	21.9	16.1	83.9	31.3
I. garbonensis	2.6	15.6	22.0	78.0	32.0
Paddock	3.0	15.7	18.9	81.1	35.4
C. plectostachyus	2.2	19.0	15.8	84.2	22.7
LSD	NS	NS	2.44	2.44	2.7

NB: OM = Organic matter; Means with the same letters in each column, are not significantly different at 5% level of probability; NS = not significant.

Table 5
Soil erodibility factor (K) as influenced by conservation measures.

Conservation Measure	USLE Erodibility		WEPP Erodibility	
	Wischmeier and Mannering	El-Swaify and Dangler	Inter-rill	Rill
I. wombulu	1.25	0.11	2.98	0.41
I. garbonensis	0.95	0.07	2.62	0.30
Paddock	1.10	0.09	2.72	0.38
C. plectostachyus	1.37	0.17	3.13	0.45
LSD	NS	0.08	NS	NS

NB: OM = Organic matter; Means with the same letters in each column, are not significantly different at 5% level of probability; NS = not significant.

Table 6
Erodibility Class of Conservation Measures at Study location.

Soil erodibility class	Erodibility risk	K Range	Soil Conservation Strategy	
			USLE	WEPP
K1	Very Low	0.00–0.10	*I. garbonensis* and Paddock	
K2	Low	0.11–0.20	*I. wombulu* and *C. plectostachyus*	
K3	Moderate	0.21–0.30		*I. garbonensis*
K4	Moderately High	0.31–0.40		Paddock
K5	High	0.41–0.50		*I. wombulu* and *C. plectostachyus*
K6	Very High	>0.50		

USLE = Universal Soil Loss Erodibility; WEPP = Water Erosion Prediction Project.

3.3. Correlation between soil erodibility and soil properties under different soil conservation measures

The correlation between soil erodibility and selected soil physical indicators under the different soil conservation measures are presented in Table 7. In *Irvingia wombulu*, there was strong relationship between USLE erodibility factors the soil physical indicators (sand, silt, BD and total porosity). Silt (r = 0.998) was significantly ($p \leq 0.05$) correlated with Wischmeier and Mannering USLE erodibility factor. BD (r = 0.99) had high correlation with WEPP erodibility (inter-rill and rill). There was an irregular pattern in the

Table 7
Establishing correlation between Erodibility with selected soil physical properties.

Soil Conservation Strategy	Erodibility	Sand	silt	Clay	Bulk density (Mg/m^3)	TP
I.wombulu	Inter-Rill Erodibility	−0.14	−0.16	0.61	0.99	−0.13
	Rill Erodibility	0.00	−0.18	0.62	0.99	−0.14
	Wischmeier and Mannering	−1.0	0.998*	−0.91	−0.37	1.00
	El-Swaify and Dangler	−0.84	0.73	−0.32	0.42	0.76
I.garbonensis	Inter-Rill Erodibility	−0.01	−0.09	0.15	−0.57	0.33
	Rill Erodibility	0.00	−0.10	0.14	−0.58*	0.34
	Wischmeier and Mannering	0.10	0.05	−0.26	0.07	0.01
	El-Swaify and Dangler	−0.53	0.582*	0.16	−0.14	0.05
Paddock	Inter-Rill Erodibility	−0.01	−0.16	0.61	0.99	−0.92
	Rill Erodibility	0.00	−0.18	0.62	0.99	−0.91
	Wischmeier and Mannering	−0.97	0.998*	−0.91	−0.37	−0.19
	El-Swaify and Dangler	−0.84	0.73	−0.32	0.42	−0.84
C. plectostachyus	Inter-Rill Erodibility	−0.61	−0.05	0.95	0.89	0.96
	Rill Erodibility	0.61	−0.06	0.95	0.89	0.96
	Wischmeier and Mannering	−0.59	0.08	−0.94	−0.90	0.96
	El-Swaify and Dangler	−0.17	0.52	−0.70	1.00*	0.98

NB: TP = Total Porosity: * = Significant at 5%; ** = Significant at 1%.

correlation between soil erodibility factors and soil physical indicators in *Irvingia garbonensis* (Table 7). Elswaify and Dangler USLE erodibility had a positive significant ($p \leq 0.05$) correlation with Silt (r = 0.58); while WEPP rill erodibility had a negative significant ($p \leq 0.05$) relationship with BD (r = −0.58).

In paddock soil conservation measure, the two USLE erodibility factors had negative correlations with sand (r = −0.97 for Wischmeier and Mannering; r = −0.84 for Elswaify and Dangler) and clay (r = −0.91 for Wischmeier and Mannering; r = −0.32 for Elswaify and Dangler) respectively. Wischmeier and Mannering USLE erodibility factor had a strong positive significant (p ≤ 0.05) relationship with silt (r = 0.998). Also BD (r = 0.99) had a strong relationship with WEPP (interill and rill) erodibility while total porosity negatively correlated with WEPP erodibility (r = −0.92 for inter-rill; r = −0.91 for rill). In *Cynodon plectostachyus* soil conservation measure, Clay had strong correlations with Wischmeier and Mannering (r = −0.94), Elswaify and Dangler (r = −0.70) USLE erodibility and rill (r = 0.95) and inter-rill (r = 0.95) WEPP erodibility. BD (r = 1.0) had a perfect positive significant (p ≤ 0.05) correlation with Elswaify and Dangler USLE erodibility, and strong correlations with rill (r = 0.89) and inter-rill (0.89) WEPP erdodibility factors. Similarly, total porosity had strong correlations with Wischmeier and Mannering (r = 0.96), Elswaify and Dangler (r = 0.98) USLE erodibility and rill (r = 0.96) and inter-rill (r = 0.96) WEPP erodibility.

Furthermore, the correlation of soil erodibility with soil chemical indicator among the soil conservation measures was presented in Table 8. In *Irvingia wombulu*, total nitrogen (r = 0.995) and organic matter (r = 0.846) were strongly correlated with rill and inter-rill erodibility factors, while available phosphorus (r = 1.00) was significantly (p ≤ 0.05) correlated with Wischmeier and Mannering's USLE erodibility factor. Exchangeable acidity (r = 0.996), Ca (r = 0.996) and K (r = −0.996) correlated highly with Elswaify and Dangler's USLE erodibility factor.In *Irvingia garbonensis*, total nitrogen (r = 0.718) had a significant (p ≤ 0.05) correlation with Wischmeier and Mannering USLE's erodibility factor, however, there were low correlation between other chemical properties (available P, exchangeable acidity, calcium, potassium and organic matter) with both USLE and WEPP erodibility factors.

Similar to *Irvingia wombulu*, total nitrogen (r = 0.995) and organic matter (r = −0.984) were strongly correlated with rill and inter-rill WEPP erodibility factors, while available phosphorus (r = 1.00) was significantly (p ≤ 0.05) correlated with Wischmeier and Mannering's USLE erodibility factor. Exchangeable acidity (r = 0.996), Ca (r = 0.709) and K (r = −0.996) correlated highly with Elswaify and Dangler's USLE erodibility factor. However, in *Cynodon plectostachyus*, organic matter was significantly (p ≤ 0.05) correlated with rill (r = 0.998), inter-rill (r = 0.998), Wischmeier and Mannering (r = 0.999) erodibility factors, but strongly correlated with Elswaify and Dangler (r = 0.913) erodibility factor. Also, available phosphorus had high relationship with rill (r = 0.986), inter-rill (r = 0.987), Wischmeier and Mannering (r = 0.984) and least with Elswaify and Dangler (r = 0.795) erodibility factors. Exchangeable acidity also had correlated highest with Wischmeier and Mannering (r = 0.984) and least with Elswaify and Dangler (0.959). Total nitrogen correlated highest with inter-rill (r = −0.91), rill (r = −0.908), Wischmeier and Mannering (r = −0.9) and least with Elswaify and Dangler (r = −0.609) erodibility factors.

Correlation between soil erodibility and selected erosion indices under different soil conservation measures.

The correlation between soil erodibility and selected soil erosion indices under the different soil conservation measures are presented in Table 9. In *Irvingia wombulu,* the ratio of silt:clay had the highest correlation with Wischmeier and Mannering (r = 0.99) and least with inter-rill (r = −0.34) erodibility. Clay ratio was highly correlated with Wischmeier and Mannering (r = 0.95) and least with Elswaify and Dangler (r = −0.44) erodibility factor. Unstable aggregate correlated highest in Wischmeier and Mannering (r = −0.97) and least correlated with rill (r = −0.01) and inter-rill (r = −0.01) erodibility factors. In *Irvingia garbonensis*, the ratio of silt-clay correlated highest in Wischmeier and Mannering (r = 0.33) and least in El-Swaify and Dangler (r = 0.14) erodibility factor. Clay ratio was significantly (p ≤ 0.05) correlated with Elswaify and Dangler (r = −0.77) USLE erodibility factor, and was least correlated with rill (r = −0.01) WEPP erodibility factor. Unstable aggregates gave its highest correlation with Elswaify and Dangler (r = −0.28)

Table 8
Establishing covariation between erodibility and selected soil chemical properties under different soil conservation strategies.

Soil Conservation Strategy	Erodibility	Soil Chemical Properties					
		TN (g/kg)	Avail.P (mg/kg)	EA (cmol/kg)	Ca (cmol/kg)	K (cmol/kg)	O.M (g/kg)
I. wombulu	Inter-Rill Erodibility	0.995	−0.206	0.626	0.111	−0.626	0.846
	Rill Erodibility	0.994	−0.219	0.616	0.125	−0.616	0.853
	Wischmeier and Mannering	−0.123	1.00**	0.622	−0.994	−0.622	−0.706
	El-Swaify and Dangler	0.633	0.702	0.996	0.996	−0.996	0.024
I.garbonensis	Inter-Rill Erodibility	0.003	0.141	−0.14	0.227	−0.053	−0.008
	Rill Erodibility	0.014	0.154	−0.137	0.243	−0.038	0.004
	Wischmeier and Mannering	0.718**	0.077	0.326	0.017	−0.301	−0.173
	El-Swaify and Dangler	0.212	0.133	−0.054	−0.006	−0.242	−0.028
Paddock	Inter-Rill Erodibility	0.995	−0.206	0.626	0.98	−0.626	−0.984
	Rill Erodibility	0.994	−0.219	0.616	0.977	−0.616	−0.981
	Wischmeier and Mannering	−0.123	1.00**	0.622	−0.021	−0.622	0.042
	El-Swaify and Dangler	0.633	0.702	0.996	0.709	−0.996	−0.693
C. plectostachyus							
	Inter-Rill Erodibility	−0.91	0.987	0.98	0.536	0.546	0.998*
	Rill Erodibility	−0.908	0.986	0.981	0.541	0.551	0.998*
	Wischmeier and Mannering	−0.9	0.982	0.984	0.556	0.566	0.999*
	El-Swaify and Dangler	−0.609	0.795	0.959	0.869	0.875	0.913

NB: TN = Total Nitrogen; EA = Exchangeable Acidity; * = Significant at 5%; ** = Significant at 1%.

Table 9
Establishing correlation between erodibility and erosion indices under different soil conservation strategies.

Soil Conservation Strategy	Erodibility	Erodibility Indices		
		Silt: Clay	Clay ratio	Unstable Aggregate
I.wombulu	Inter-Rill Erodibility	−0.34	0.50	−0.01
	Rill Erodibility	−0.35	0.51	−0.01
	Wischmeier and Mannering	0.99	0.95	−0.97
	El-Swaify and Dangler	0.60	−0.44	−0.84
I.garbonensis	Inter-Rill Erodibility	−0.21	−0.03	−0.21
	Rill Erodibility	−0.21	−0.01	−0.21
	Wischmeier and Mannering	0.33	−0.17	−0.11
	El-Swaify and Dangler	0.14	−0.77**	−0.28
Paddock	Inter-Rill Erodibility	−0.34	0.50	−0.35
	Rill Erodibility	−0.35	0.51	−0.35
	Wischmeier and Mannering	0.99	−0.95	−1.00*
	El-Swaify and Dangler	0.60	0.42	−0.70
C. plectostachyus	Inter-Rill Erodibility	0.999*	−1.00*	0.61
	Rill Erodibility	0.999*	−1.00*	0.61
	Wischmeier and Mannering	1.00*	−1.00*	0.30
	El-Swaify and Dangler	0.90	−0.86	0.17

NB: * = Significant at 5%; ** = Significant at 1%.

and least with Wischmeier and Mannering (r = −0.11) erodibility factor.

Furthermore, in paddock, the ratio of silt-clay gave highest correlation with Wischmeier and Mannering (r = 0.99) and least with inter-rill (r = −0.34) erodibility factor. Clay ratio had its highest relationship with Wischmeier and Mannering (r = −0.95) and least with Elswaify and Dangler (r = 0.42) erodibility factor. Unstable aggregate was had a perfect significant ($p \leq 0.05$) correlation with Wischmeier and Mannering (r = −1.0), but was least correlated with both rill (r = −0.35) and inter-rill (r = −0.35) erodibility factors. In *Cynodon plectostachyus*, the ratio of silt-clay gave significant ($p \leq 0.05$) correlations with Wischmeier and Mannering (r = 1.00), inter-rill (r = 0.99), and rill (r = 0.99), but was least correlated with Elswaify and Dangker (r = 0.90) erodibility factor. Clay ratio gave perfect significant ($p \leq 0.05$) relationships with inter-rill (r = −1.00), rill (r = −1.00) and Wischmeier and Mannering (r = −1.00) erodibility factors, but was least correlated with Elswaify and Dangler (r = −0.86) erodibility factor. Unstable aggregate correlated highest with rill (r = 0.61) and inter-rill (r = 0.61) WEPP erodibility factors, and least with Elswaify and Dangler (r = −.17) USLE erodibility factor.

The correlation of erodibility factors was presented in Table 10. Elswaify and Dangler had the highest correlation with Wischmeier and Mannering (r = 1.00), inter-rill (r = 0.754) and rill (r = 0.754) erodibility factors, while Wischmeier and Mannering gave the least correlation with rill (r = 0.308) and inter-rill (r = 0.308) WEPP erodibility factors.

4. Discussion

The textural classes of the soils under the different soil conservation systems was loamy sand, which entails that the soils are coarse textured using the USDA soil textural class ratings [22]. The non-significance of the bulk density and total porosity across the soil conservation measures could be attributed to the similarities in their textural class and clay content. Oshunsanya [25] noted that soils with similar textural class are prone to possess similar soil physical characteristics like bulk density and porosity. The higher soil organic carbon content observed in paddocking could be due to the presence of organic materials (like feaces, litters etc.) from the animals. Ezeaku [26] reported that soils with organic inclusions from animals tend to possess higher organic carbon contents. The significant variation in the available phosphorus content of the soils could be due to the significant change in the organic matter contents of the soils under the various soil conservation measures. *I. garbonensis* with the highest P – content indicated that there was lesser leaching of P in the soils. The significant variations in the exchangeable bases (Ca, Mg, and K) across the soil conservation measures could be due to the variation in the organic matter and available P contents respectively. The concept of nutrient antagonism which establishes the impediments to the presence of some nutrients, when concentrations of others are higher could be responsible for

Table 10
Correlation of erodibility indices in study area.

	Wischmeier and Mannering	El-Swaify and Dangler	Inter-Rill Erodibility	Rill Erodibility	Unstable Aggregate	Stable Aggregate
Wischmeier and Mannering						
El-Swaify and Dangler	1.00					
Inter-Rill Erodibility	0.3077	0.7538				
Rill Erodibility	0.3077	0.7538	1.00			
Unstable Aggregate	0.0977	−0.5245	−0.0084	−0.0084		
Stable Aggregate	−0.0977	0.5245	0.0084	0.0084	1.00**	

the significant differences in the exchangeable bases across the soil conservation measures in the study area [27].

Furthermore, the significant difference between the erodibility indices – unstable and stable aggregates could be due to the difference in the soil organic matter content of the soils under the different soil conservation measures. Lal [24] and Oshunsanya and Nwosu [2] noted that there is a direct relationship between soil organic matter and soil stability and vice versa. The non-significant difference in the silt:clay and clay ration could be attributed to the similarities in their soil physical properties like texture and clay content respectively. Of the four soil conservation measures used in this study *I. garbonensis* had the most stable soil aggregates, implying that soil under this conservation measure was require higher erosivity to be detached and transported, this is closely followed by soils under paddock, *I. wombulu* and grassland with the lease stability. Also, it is observed that *I. garbonensis* increased soil aggregation more than the other soil conservation measures adopted in the area. Oshunsanya [25] maintained that the higher the soil stability, the lesser the susceptibility of the soil to erode.

The erodibility factor of the soils under the various soil conservation measures significantly differed in El-Swaify and Dangler USLE erodibility factor. Although, there were variations in the WEPP erodibility factor, it was however not significant. The significant changes in the USLE erodibility factors could be attributed to the changes in the erodibility indices like organic matter and soil stability. These two factors greatly influence soil erodibility in any soil type [5]. Oshunsanya and Nwosu [2,4] noted that the lesser the erodibility factor, the lower the ease of erosion to occur. *I. garbonensis* had the least erodibility factor, which indicates a lesser propensity to erode. This could be due to the higher organic matter and lesser percentage of unstable aggregates of the soils under this method of soil conservation. Oshunsanya and Nwosu [4] observed in a study that the use of USLE erodibility factor gave more precision in predicting soil erodibility for tropical soils in southwestern Nigeria. Hence, the significant variation in the USLE erodibility observed in this study entails that the soil conservation measures influenced soil erodibility in the area.

With regards to the erodiblity risk, under the USLE erodibility, *I. garbonensis* and Paddock belong to the K1 class which indicates very low erodibility risk, while *I. wombulu* and grassland were low in erodibility risk. Conversely, under the WEPP erodibility, *I. garbonensis* belonged to the class of moderate erodibility risk (K3) and this followed by paddock with moderately high erodibility risk. *I, wombulu* and grassland were rated to have high erodibility risk. This could be due to the lower soil aggregate stability and organic matter content of the soils under the conservation measures. *I. garbonensis* under both USLE and WEPP erodibility models had the least propensity to be eroded owing to their erodibility factors respectively.

There were significant relationships on erodibility and soil physical properties for the various soil conservation measures in the study area. Nevertheless, across the entire soil conservations measures, silt was significantly correlated with erodibility in *I. wombulu, I. garbonensis* and paddock under the USLE erodibility factor. Conversely, bulk density (BD) and silt were the two highly correlated soil properties with all four (4) soil conservation measures. The result obtained could be attributed the relevance of silt and sand which forms basic components of the USLE erodibility models. Soil organic matter which greatly influences the bulk density and total porosity can account for the strong relationship observed between BD and TP with WEPP erodibility factor. Also, there were significant relationships between erodibility and soil chemical properties across the soil conservation measures. Although, E.A, Ca and K gave high correlations with erodibility, available P and organic matter (O.M) showed significant association with USLE erodilbility factors across the soil conservation measures. Also, T.N and O.M gave strong significant correlations with the WEPP erodibility factors across the soil conservation systems used in the study area. The strong correlations of erodibility and selected soil chemical properties could be as a result of the influence of the various soils conservation measures on soil chemical properties. Paddock technique is known to increase O.M content while the use of *I. wombulu*, *I. garbonensis* also tends to reduce the leaching of available phosphorus and reduced impact of rainfall erosivity for erosion to occur across the field. Oshunsanya and Nwosu [4] noted that live mulch and cover crops serve as physical impedance for erosion management in the field. The use of *I. garbonensis* and *I. wombulu* tend to protect the soils by providing adequate cover against the direct impact of rainfall when compared to grasslands, thereby reducing runoff and leaching of nutrients in the soils.

More so, there were high correlations between selected soil erosion indices with soil erodibility across the soil conservation measures. The ratio of silt:clay, clay ratio and unstable aggregates significantly related to USLE erodibility factors, while there was only strong significant correlation between the erosion indices and WEPP erodibility factors under grassland conservation system. The strong relationship observed with the USLE erodibility factors could be attributed to the pertinence of silt and clay relationships in USLE erodibility factor models. WEPP erodibility tends to consider the impacts of O.M on the soils propensity to be dislodged by the erosive force of rainfall, thereby laying little importance to the textural composition of the soil for erosion management studies [5]. The strong correlation between Elswaify and Dangler USLE erodibility factor with the inter-rill and rill WEPP erodibility factors could be as a result of the similarities in their prediction model indices and the high level of prediction precision obtainable with Elswaify and Dangler's USLE erodibility model. This was similar to earlier studies by Ref. [4], where Elswaify and Dangler's USLE model for erosion prediction correlated more with theWEPP rill and inter-rill erodibility factors respectively. They also observed that the Elswaify and Dangler's USLE model gave more precision in erosion prediction for most soil types in south western Nigeria. The result of this study also consolidates on the pre-existing premise of the efficiency of the use of Elswaify and Dangler's USLE erodibility factor in erosion studies in southwestern Nigeria.

5. Conclusions

Erosion accounts for more than 80% of land degradation especially in the tropical regions of sub-Sahara Africa. This has declined soil quality, influenced crop yields and increased cost of production for most of the small-scale resource farmers in Africa. The use of soil conservation measures to checkmate against erosion becomes increasingly pertinent for sustainable agriculture. This study assessed the effects of soil conservation measures on soil erodibility and soil properties in the National Centre for Genetic Resources and Biotechnology (NACGRAB) in Ido Local Government Area of Oyo state, Southwestern Nigeria. *I. garbonensis* soil conservation measure gave the least erodibility factor ($K = 0.07$), among paddock ($K = 0.09$) *I. wombulu* ($K = 0.11$) and *C. plectostachyus* with the highest erodibility factor ($K = 0.17$), indicating that *I. garbonensis* has the highest potential for soil conservation. Soil conservation measures significantly ($p \leq 0.05$) influenced soil properties like organic carbon, available phosphorus, exchangeable bases (calcium, magnesium, potassium, and sodium), sand, silt and aggregate stability. Wischmeier and Mannering's USLE erodibility and WEPP's rill and inter-rill erodibility were not significantly ($p \geq 0.05$) different across the soil the soil conservation measures. Elswaify and Dangler's USLE erodibility correlated best with Wischmeier and Mannering USLE erodibility ($r = 1.00$) and WEPP's rill ($r = 0.8$) and inter-rrill ($r = 0.8$) erodibility. Also, soil properties (sand, silt, organic carbon, available phosphorus and aggregate stability) significantly ($p \leq 0.05$) correlated with USLE erodibility factor. Elswaify and Dangler USLE erodibility gave higher precision in erodibility determination of the soils.

I. garbonensis was the best soil conservation measure for sustainable agriculture, indicating that the use of this measure is considered more efficient in reducing soil erosion in the area. The study affirms the conservation measure, is cheap, efficient and reliable in safeguarding alfisols in Nigeria for better erosion control and improved soil productivity for sustainable crop production and environmental sustainability. Also, in light of the easy access, establishment and maintenance of *I. garbonensis*, it is a well recommended for soil erosion control by smallholder farmers on tropical alfisols.

Author contribution statement

Nkem Joseph Nwosu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Abisoye Ojo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Saurau Oshunsanya; Inioluwa V. Ayantayo-Ojo; Sunday E. Aladele: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

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