Assessment of Simple Engineering Approaches and Poultry Manure for Soil Erosion Control Under Maize Cultivation in the Tropics

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ABSTRACT: Monitoring soil erosion is crucial for soil conservation policies, especially in tropical regions that are prone to water erosion. A 2-year field study was conducted to assess the impact of simple engineering approaches and poultry manure application on soil loss, soil physical properties, maize yield, and economic benefit in Southwest Nigeria. The experiment was a 4 × 2 factorial arrangement with three replications. The treatments included four engineering approaches (surface mat, silt fencing, furrow dike, and no approach [control]) and two poultry manure application rates at 0 and 20 t ha⁻¹. Annual soil loss was higher under the control (6.22–8.01 Mg ha⁻¹ year⁻¹). The combination of engineering approaches with poultry manure at 20 t ha⁻¹ significantly ($p \leq .05$) reduced soil loss by 9.7% to 85.4% compared to control. Engineering approaches and poultry manure application did not significantly improve soil physical properties; however, saturated hydraulic conductivity was highest under surface mat combined with poultry manure at 20 t ha⁻¹ in both years. Maize yield increased by 27.7% under surface mat compared to control, while an additional grain yield of 0.14 Mg ha⁻¹ was obtained for 20 t ha⁻¹ poultry manure over 0 t ha⁻¹. Soil loss was negatively and significantly correlated with grain yield. The results suggest that integrating surface mats with poultry manure can be effective in controlling soil loss, enhancing soil properties, and improving maize yield.

KEYWORDS: Water erosion, soil loss, soil conservation, maize yield, sustainable agriculture

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Introduction

The burgeoning global population has compelled for higher deforestation and cultivation on marginal lands, leading to diminished production, reduced biodiversity, and increased soil degradation (Tully et al., 2015). Healthy soils can sustain a variety of ecosystem services, including soil carbon storage and nutrient status, water storage, soil microbial population and biodiversity (Anikwe & Ife, 2023; Hou, 2023; Lal, 2016), and sustainably livelihood support (Bagnall et al., 2021). These attributes highlight the significance of mitigating soil degradation.

Soil erosion contributes to the global degradation of soil health and ecosystem functions (Xiong & Leng, 2024). The impact of soil erosion by water is exacerbated by topographical factors (slope length and steepness), anthropogenic activities (land use change), and climate change (rainfall amount and intensity; Panagos et al., 2016). Beyond the immediate loss of soil and nutrients, erosion results in on- and off-site damages such as sedimentation of water bodies, impairing water quality, and aquatic habitats (Remund et al., 2021; Zhao et al., 2024). This erosion-induced loss of fertile topsoil reduces soil productivity, leading to decreased crop yields and agricultural viability (Bashagaluke et al., 2018). An economic assessment by Sartori et al. (2019) shows that soil erosion has a negative impact on the macroeconomy, with a monetary loss of about 8 billion US dollars of GDP. Unfortunately, the global amount of soil erosion is projected to increase, with an estimate of 43×10^9 Mg year⁻¹ by the year 2070 (Borrelli et al., 2017) and could reduce land productivity.

Agricultural lands exhibit high soil erosion rates, predominantly due to inappropriate farming practices, particularly crop cultivation on slopy lands, and poor implementation of protective measures (Nasir Ahmad et al., 2020). Globally, about 24% of the arable land (3.4×10^6 km²) is under severe erosion, with more than 11 t ha year⁻¹ soil loss (Sartori et al., 2019). This loss of arable lands to erosion is more severe in the tropics (Sartori et al., 2019). Abundant evidence has shown that biological measures such as vegetation cover and mulching, largely contribute to the control of soil loss by water erosion (Labrière et al., 2015; Nafi et al., 2020; Oliveira et al., 2024). These soil and water conservation approaches have been proven to be sustainable and economical, facilitating easy adoption by farmers (Betela & Wolka, 2021). However, the mixed cropping system used for erosion control encourages competition for nutrients, water, and radiation, thereby reducing productivity and resource use efficiency of the economic crop (Cui et al., 2020; Qin et al., 2022; Wiedenfeld et al., 1999).

An important agricultural practice is animal manure application, which is well recognized for its agronomic benefits, including its potential to supply soil nutrients, increase biological activities, and improve physical properties (Rayne & Aula, 2020; Shakoor et al., 2021). Studies have shown that poultry manure improves indices of soil aggregate stability, such as mean weight diameter, clay dispersion ratio, and flocculation index, which are key indicators for soil erosion resistance (Agbede, 2021; Feng et al., 2019; Zhang et al., 2021). However, there is paucity of data on the influence of animal manure on soil erosion (Watts et al., 2023).

Conversely, engineering approaches involve the construction of physical structures on the farmland and have been reported to effectively reduce soil erosion. For example, a well-constructed and maintained terrace can reduce slope length and steepness, thereby reducing the energy of runoff (Deng et al., 2021). Previous studies also confirmed that contour farming improves soil conservation (Nasir Ahmad et al., 2020; Saggau et al., 2023). Similarly, agro-geotextile serves as an alternative to vegetative cover and has been reported to improve soil structure and aggregates, thereby reducing soil loss (Roy et al., 2023; Singh et al., 2019). These engineering approaches offers immediate and durable protection against severe soil loss and runoff, particularly in high-risk areas with steep slopes or extreme weather conditions, where biological measure alone may be inadequate (Ellis et al., 2022).

Monitoring soil loss using different approaches in an experimental setup is crucial for soil conservation policies, especially in Sub-Saharan Africa (SSA), where food production is largely affected by soil health degradation and climate change (Ediş et al., 2023). An estimated 3% reduction in the annual agricultural productivity and monetary loss of about nearly USD 68 billion monetary loss were attributed to soil degradation in SSA (Kihara et al., 2020; Zingore et al., 2015). The high rainfall intensity and duration, combined with poorly developed soils contribute to the high soil erosion risks in SSA (Ezeh et al., 2024). For instance, recent studies across different regions in Nigeria have recorded potential soil losses as high as 48 t ha^{-1} year^{-1} (Makinde & Oyebanji, 2020), >756.6 t ha^{-1} year^{-1} (Olusa et al., 2019), 889 t ha^{-1} year^{-1} (Olorunfemi et al., 2020), 1,200 t ha^{-1} year^{-1} (Dike et al., 2018), 1,373.79 t ha^{-1} year^{-1} (Amah et al., 2020), and 2,200 t ha^{-1} year^{-1} (Fagbohun et al., 2016). Although studies have shown that the use of biological or engineering measures individually can reduce soil erosion (Obi & Uwanugo, 2020; Ojo et al., 2023; Oshunsanya et al., 2023; Sule et al., 2023), to the best of our knowledge, integrating an engineering approach with poultry manure has not yet been reported.

Therefore, we hypothesized that combined technique of simple engineering approach with poultry manure would reduce soil loss and improve crop yield, thereby promoting sustainable land use. Thus, this study aims to determine the effects of simple engineering approaches and poultry manure application on soil loss, soil physical properties, and maize yield across two growing seasons.

Materials and Methods

Site description

The experiment was conducted in 2019 (September–December) and 2020 (June–September) at the Federal University of Agriculture, Abeokuta, located in the Southwest region of Nigeria. The study area falls within a transition forest to savanna zone (Sotona et al., 2014) with geographical coordinates of 7°13′74″N, 3°23′43″, and 170 m altitude. The soil was described as Plinthic Kandiudalf (Soil Survey Staff, 2021). Prior to the study, the research field was fallow for 5 years, predominantly covered with savanna shrubs and grasses. The graphical representation of the study location is presented in Busari (2017).

Table 1. Description of the Engineering Approaches.

SIMPLE ENGINEERING APPROACHES	DESCRIPTION
Furrow dike	Furrow diking-forming mounds was built between crop rows at 1 m interval along the slope. This helps to retain water and prevent soil loss. The furrow dike was constructed in the first year of the experiment.
Silt fence	This barrier was made using polyethylene and anchored to vertical wooden posts. Poles were constructed at the four diagonal sides of the plot covered with polythene nylon to surround the plot. It was fastened with ropes and nail, firmly fastened into the ground to ensure firmness against wind or external forces.
Surface mat	This is a form of agro-geotextiles source from construction wastes. The synthetic bag is permeable to water and was laid on soil surface. The mats were pegged to the ground to ensure uncovering by wind. Spaces were created at maize plating holes to ensure germination and growth of the maize.
No approach (control)	The plots were left bare under maize stands without any engineering approach in controlling soil erosion

Experimental design and treatments

The 2-year field study was established on a 12% slope gradient using a 4 × 2 factorial experiment and arranged in a randomized complete block design to reduce the heterogeneity of the experimental units arising from the slope. The first factor was simple engineering approaches to erosion control (surface mat, furrow dike, silt fencing, and no approach [control]), and the second factor was poultry manure application (PM) at 0 and 20 t ha^{-1}, with three replications. The poultry manure treatment was applied within the main plots. The erosion control methods used in the study were described in Table 1 and pictorial representation in Figure 1.

Each experimental plot had a dimension of 5 m × 4 m (20 m^2). Poultry manure was collected from a battery cage system poultry farm and cured by air-drying. The poultry manure was incorporated into the soil manually with a hoe at 2 weeks prior to planting in both study years. The manure applied had

Figure 1. Pictorial view of the engineering approaches. Silt fence (a), Furrow dike (b), Surface mat (c), No approach (Control) (d).

a chemical composition of neutral pH of 6.80, along with high levels of organic matter and total nitrogen, measured at 65.40 and 34.70 g kg^{-1}, respectively. It also contained 18.18 g kg^{-1} of total phosphorus, 16.40 g kg^{-1} of potassium, and a carbon to nitrogen ratio of 1.09.

Maize management

The maize variety, SUWAN-1-SR-Y, was sourced from a premier seed store in Nigeria. It has a yellow coating, disease resistance, and is early maturing. The seeds were planted at a spacing of 75 cm × 25 cm. Two seeds were planted and were later thinned to a seedling after a week to achieve a population of 53,333 plants per hectare. Planting of the first maize seeds was done in September 2019 and the second sowing in June 2020. The late planting in 2019 was due to the delay in seed procurement. Inorganic fertilizer (NPK 15:15:15) at a rate of 120 kg N ha^{-1} was applied 4 weeks after planting (Tofa et al., 2022). Weeds were controlled manually using a hoe at 3 and 6 weeks after planting. During the dry season in 2019, water was supplied to the plants by irrigation while the plants were rainfed during the wet season. The maize stood for 4 months in both study years (August 12–December 7, 2019 and June 15–September 9, 2020). After harvest, the maize cobs were oven dried at 70°C for 7 days, and maize yield was determined after separating the grains from the cobs.

Installation of erosion pin and erosion plots

Graduated soil erosion pins of height 45 cm and diameter 1.5 cm were used to monitor the soil erosion rate. This is a simple and effective method for monitoring the changes in the altitude of the ground surface that are due to erosion and deposition (Haigh, 1977). Two soil pins were installed along the slope at 2 m intervals along the slope of each plot and inserted into the soil at 15 cm depth while 30 cm was above the soil surface. The differences in the soil pin height above the soil surface were recorded fortnightly and averaged per plot. The difference in pin height was measured using the measuring tape. An increase in the value of the soil pin's height (positive value) is tantamount to soil erosion, while a decrease in the pin's height (negative value) is attributed to soil deposition, denoted as aggradation.

The setup of the soil erosion plot is based on earlier work by Hellin (2016). The erosion plots were sized 5 m × 2 m and had a catch pit lined with polythene nylon at the bottom. Erosion plot was constructed for each plot as a benchmark to determine the soil loss for each rainfall. The catchpits were covered with tarpaulin nylon that was intended to collect the eroded soil particles. Small holes were made to drain collected water from the catchpits. Small ridges and galvanized sheets were used to direct soil and water into the catchment pits and prevent flows from outside. Eroded soil samples collected at the catchment area were taken to the laboratory and oven dried at 105°C to constant weight. The weight of the dried soils was recorded to estimate the mass of soil loss.

Estimating soil loss

The annual soil loss was calculated using Revised Universal Soil Loss Equation (RUSLE; Wischmeier & Smith, 1965). The RUSLE formular is given in Equation (1).

$$A = RKLSCP \tag{1}$$

Where A is the estimate annual soil loss due to water erosion ($t\,ha^{-1}\,year^{-1}$), R is the rainfall erosivity factor, K the erodibility factor ($t\,ha^{-1}$), while LS, C, and P are topographic factors (slope length and steepness), cover management factor, the support practices factor, respectively and are dimensionless.

The rainfall erosivity factor (R) evaluates the erosive impacts by rainfall, and majorly depends on the rainfall's intensity and amount. The erosivity factor was derived using Fourier index (Suhara et al., 2023) in Equation (2).

$$Fourier\ index = \frac{MM^2}{MA} \tag{2}$$

Where MM represents the maximum rainfall (monthly) in mm, and MA represents annual rainfall (mm)

The soil erodibility (K) defines the resistance of soil to the erosive impacts of rainfall and largely dependent on soil characteristics and properties. The soil erodibility factor was derived using the soil erodibility nomograph and formulae (Equation 3) for cases where the silt fraction is not more than 70% (Wischmeier & Smith, 1978).

$$K = [2.1 * 10^{-4} * (12 - A) * M^{1.14} + 3.25(B - 2) + 2.5(C - 3)] / 100 \tag{3}$$

Where A is the percent organic matter, B is the structure code, C is the permeability class, and M is the product of the percent of all soil fractions other than clay and the percent silt + percentage sand.

The topographic factor, slope length (L), and steepness (S) were measured with the Abney level and measuring tape and were dependent on individual plots.

The support practice (P) relates strongly with the management practices in controlling soil erosion. This is derived from the slope method described by Luvai et al. (2022).

Soil sampling and analysis

Soil samples were collected from each plot after maize harvest and analyzed for soil physical properties. Bulk density was determined using dry soil mass in core volume of $98.21\,cm^3$ (Blake & Hartge, 1986). Saturated hydraulic conductivity was determined by the constant head method described by McKenzie and Wallace (1954). Clay dispersion ratio (CDR) was determined using the procedure of particle size analysis to measure clay dispersed by sodium hexametaphosphate (TC) and clay dispersed by water (WDC; Gee et al., 2002). The clay dispersion ratio was calculated as shown in Equation 4. Higher CDR value implies higher susceptibility of soil to dispersion (Oguike & Mbagwu, 2009).

$$\text{Clay Dispersion Ratio (CDR)} = \frac{\text{WDC}}{T\text{c}} \tag{4}$$

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) and the means were separated using least significant difference at 5% level of probability. The sources of variances were engineering approaches and poultry manure. Pearson's correlation analysis was conducted to determine the relationship between soil loss, soil physical properties and maize yield averaged across the replication ($n = 24$). All statistical analysis was performed using GENSTAT 2009 software package, 12TH edition while the plots were designed in the R studio environment (R Core Team, 2022).

Results

Soil physical and chemical properties of the study location

The study location is predominant sandy ($820\,g\,kg^{-1}$) with loamy sand texture (Table 2). The mean values of the soil chemical properties included: organic carbon content; $24.10\,g\,kg^{-1}$, low total nitrogen; $1.70\,g\,kg^{-1}$, moderate available phosphorus concentration; $13.48\,mg\,kg^{-1}$ while the basic cation was dominated by Ca followed by Mg, K, and Na.

Weather attributes of the study location

The weather condition of the area has a rainy season from late March to early November and dry season from end of November to early March. There is usually an intermediate shortage of moisture in August before the high rainfall in September. The rainfall and temperature distribution during the study period are presented in Figure 2. The average temperature during the study period ranges from 23°C to 32°C for minimum and maximum temperature, respectively. The average temperature was 27.7°C which peaks between February and March. Generally,

Table 2. Initial Soil Physical and Chemical Properties of the Experimental Site.

PARAMETER	VALUE
Soil pH (water)	6.15
Sand (g kg^{-1})	820
Clay (g kg^{-1})	66
Silt (g kg^{-1})	114
Textural class	Loamy sand
Total nitrogen (g kg^{-1})	1.70
Organic carbon (g kg^{-1})	24.10
Available phosphorus (mg kg^{-1})	13.48
Ca (cmol kg^{-1})	4.94
Mg (cmol kg^{-1})	2.40
Na (cmol kg^{-1})	0.54
K (cmol kg^{-1})	0.90
Al + H (cmol kg^{-1})	0.08
ECEC (cmol kg^{-1})	8.86
Base saturation (%)	99.10

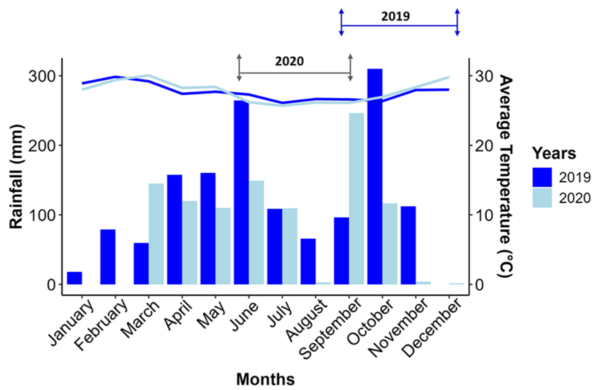

Figure 2. Amount of rainfall and mean temperature of the study area for 2019 and 2020. The rainfall amount is represented with bars while temperature with lines. The arrows indicate the period during which the experiment was conducted in both years.

the rainfall distribution in 2020 was lower compared to 2019. The total amount of rainfall received during the study in 2019 and 2020 was 518 and 507 mm, respectively. The agrometeorological data during the study period was sourced from the Department of Agrometeorological and Water Management, Federal University of Agriculture, Abeokuta.

Effect of different engineering approaches on soil loss

The soil loss was strongly influenced by engineering approaches (EA), which was highest under control (4.36 Mg ha^{-1} year^{-1} in 2019) and (5.42 Mg ha^{-1} year^{-1} in 2020; Figure 3). Surface mat significantly ($p < .05$) reduced soil loss followed by silt fencing and furrow dike in 2019. Similar result was observed in 2020 with significantly low soil loss under surface mat (1.00 Mg ha^{-1}). In both years of study, application of poultry manure (PM) at 20 t ha^{-1} reduced soil loss by 56.7% and 25.9% in 2019 and 2020, respectively. There was a significant effect of combining engineering approaches with application of poultry manure on soil loss (Table 3). Application of poultry manure at 20 t ha^{-1} consistently reduced the soil loss than the 0 t ha^{-1} under each of the engineering approaches. The integration of surface mat with application of 20 t ha^{-1} poultry manure significantly reduced soil loss than control treatment and was evident in both study years. Averaged across the treatments, soil loss was 25% lower in 2019 than 2020.

Soil loss using soil pin

Engineering approaches showed notable variations in soil loss in relation to the erosion pin height differences (Figure 4). Across the weeks in 2019, the furrow dike approach recorded significantly higher erosion control compared to the control (no approach), except at 8 weeks after planting (WAP) where surface mat recorded the highest erosion control measure. In 2020, surface mat had significantly higher soil conservation measure which was highest at 8 WAP (-0.1 cm). Notably at 6 and 8 WAP, control plot recorded the highest soil loss. Application of PM consistently reduced soil loss across the study period. In 2019, the highest soil loss was recorded at 2 WAP with 0 t ha^{-1} PM while the least soil loss was observed at 8 WAP under 20 t ha^{-1} PM with erosion height of 1.89 and 0.96 cm, respectively. Similarly in 2020, soil conservation under 20 t ha^{-1} PM application significantly reduced soil loss at 6 and 8 WAP compared to 0 t ha^{-1}.

Effect of different engineering approaches on some soil physical properties

Soil bulk density was 4.8% to 17.7% lower under the engineering approaches compared to control, however not statistically different (Table 4). Soils under surface mat had the lowest bulk density in 2019 (1.12 g cm^{-3}) and 2020 (1.15 g cm^{-3}) cropping seasons. Similarly, engineering approaches had higher total porosity compared to control and was highest under the surface mat treatment. Soil Ks was 0.7% to 19.34% and 11.4% to

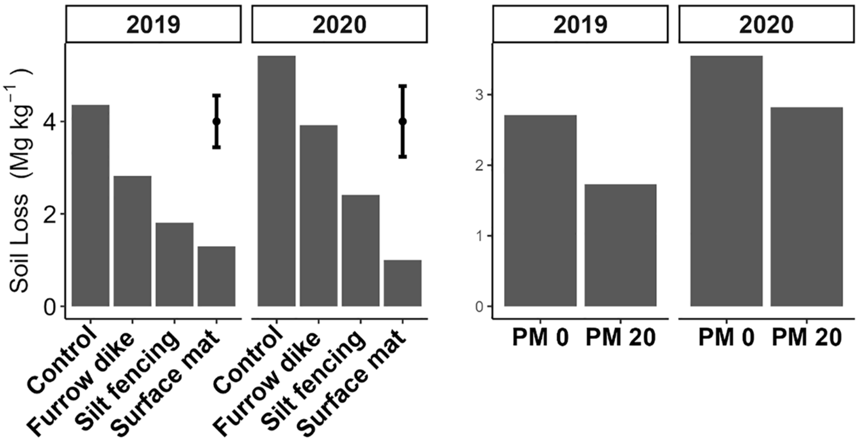

Figure 3. Effects of engineering approaches (a) and poultry manure (b) on soil loss. PM 0; Poultry manure at 0 t ha^{-1}, PM 20; poultry manure at 20 t ha^{-1}, vertical bars indicate LSD values ($p < 0.05$).

Table 3. Interactive Effects of Engineering Approaches and Poultry Manure on Annual Soil Loss.

ENGINEERING APPROACHES (EA)	POULTRY MANURE (t ha^{-1})	ANNUAL SOIL LOSS (Mg ha^{-1} YEAR^{-1}) 2019	2020
Control	0	7.51 a	8.01 a
	20	6.76 ab	6.22 b
Furrow dike	0	4.78 bc	7.26 ab
	20	3.98 c	5.62 bc
Surface mat	0	1.64 e	1.09 e
	20	1.47 e	0.91 e
Silt fencing	0	3.62 cd	2.90 cd
	20	3.06 d	1.92 de
LSD ($p \leqslant .05$)		1.51	2.18

Note. Means with different letters indicate significant differences ($p \leqslant .05$) between treatments.

42.4% higher under the engineering approaches than control in 2019 and 2020, respectively and was highest under surface mat. In 2019, CDR was not affected by the engineering approaches, however least value was recorded under furrow dike. Silt fencing had significantly lower CDR that control in 2020.

Poultry manure application did not affect BD, TP, and CDR in both years of the study. However, the application of 20 t ha^{-1} poultry manure significantly increased Ks by 17% and 11% than 0 t ha^{-1} in 2019 and 2020, respectively. The interactive effect of engineering approach and poultry manure application did not affect the soil physical properties except for Ks (Table 4). Poultry manure application increased Ks by 4.7% to 17.8% in 2019 and 0.5% to 13.7% in 2020 across the engineering approaches and was highest with the combination of surface mat and PM at 20 t ha^{-1} (Figure 5).

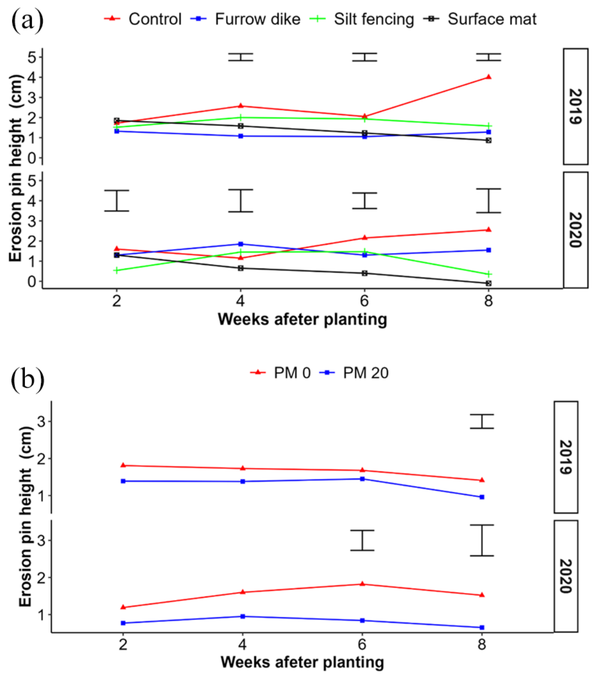

Figure 4. Erosion pin height variation across the experimental periods under engineering approaches (a) and poultry manure applications (b). PM 0; Poultry manure at 0 t ha^{-1}, PM 20; poultry manure at 20 t ha^{-1}, vertical bars indicate LSD values ($p < 0.05$) for treatment mean separation at each week.

Effect of engineering approaches and poultry manure on maize yield

The maize yield was 1.3% to 43.2% higher in the engineering approaches than the control the year (Table 5). The maize yield followed the order, surface mat > silt fencing > furrow dike > control in 2019 and surface mat > furrow dike > silt

Table 4. Effect of Engineering Approaches and Poultry Manure on Some Soil Physical Properties.

	2019				2020			
FACTORS	BD ($g cm^{-3}$)	TP (%)	KS ($cm hr^{-1}$)	CDR (%)	BD ($g cm^{-3}$)	TP (%)	KS ($cm hr^{-1}$)	CDR (%)
Engineering approaches (EA)								
Control	1.36	48.68	10.34	50.00	1.25	52.83	9.58	34.00
Furrow dike	1.18	55.47	10.41	43.00	1.19	55.09	10.67	41.00
Surface mat	1.12	57.74	12.43	57.00	1.15	56.60	13.64	48.00
Silt fencing	1.24	53.21	11.10	45.00	1.19	55.09	10.68	26.00
LSD ($p \leq .05$)	ns	ns	1.30	ns	ns	ns	1.43	19.00
Poultry manure (PM; $t ha^{-1}$)								
0	1.23	53.58	10.68	47.00	1.16	56.23	9.67	39.00
20	1.20	54.72	12.49	50.00	1.02	61.51	10.71	35.00
LSD ($p \leq .05$)	ns	ns	1.01	ns	ns	ns	1.03	ns
Interaction								
EA × PM	ns	ns	1.43	ns	ns	ns	0.61	ns

Note. BD = bulk density; TP = total porosity; CDR = clay dispersion ratio; ns = not significant.

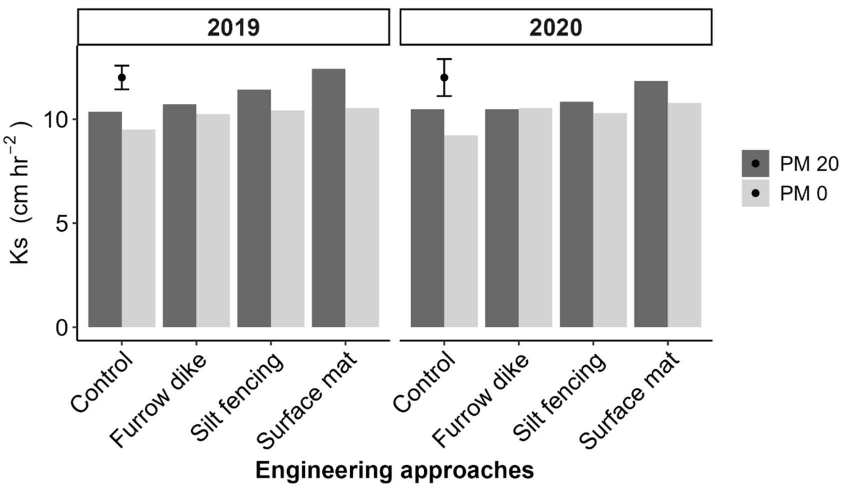

Figure 5. Interactive effect of engineering approaches and poultry manure on saturated hydraulic conductivity. PM 0; Poultry manure at 0 $t ha^{-1}$, PM 20; poultry manure at 20 $t ha^{-1}$, vertical bars indicate LSD values ($p < .05$) for treatment interactions.

fencing > control in 2020. Averaged across the engineering approach, maize yield was 0.7% to 17.1% greater at 20 $t ha^{-1}$ than 0 $t ha^{-1}$ during the study. Grain yield was 11.1% higher in 2020 than 2019, irrespective of the treatments.

Relationship between soil properties and maize yield

Pearson correlation analysis was utilized to examine the relationship between soil loss, soil physical properties and maize yield (Figure 6). In both years of study, soil loss (Sloss) was observed to have a negative and significant ($p < .05$) correlation with maize grain yield (GY). Bulk density (BD) was found to have negative correlation while total porosity (TP) and saturated hydraulic conductivity (Ks) exhibited positive correlation with grain yield. Amongst the soil properties, soil loss correlated positively with bulk density and correlated negatively with total porosity and saturated hydraulic conductivity.

Discussion

The soil in the study area were predominantly sandy, formed from coarse grained granitic parent material (Osinuga et al., 2023). The high sand characteristic indicates the vulnerability

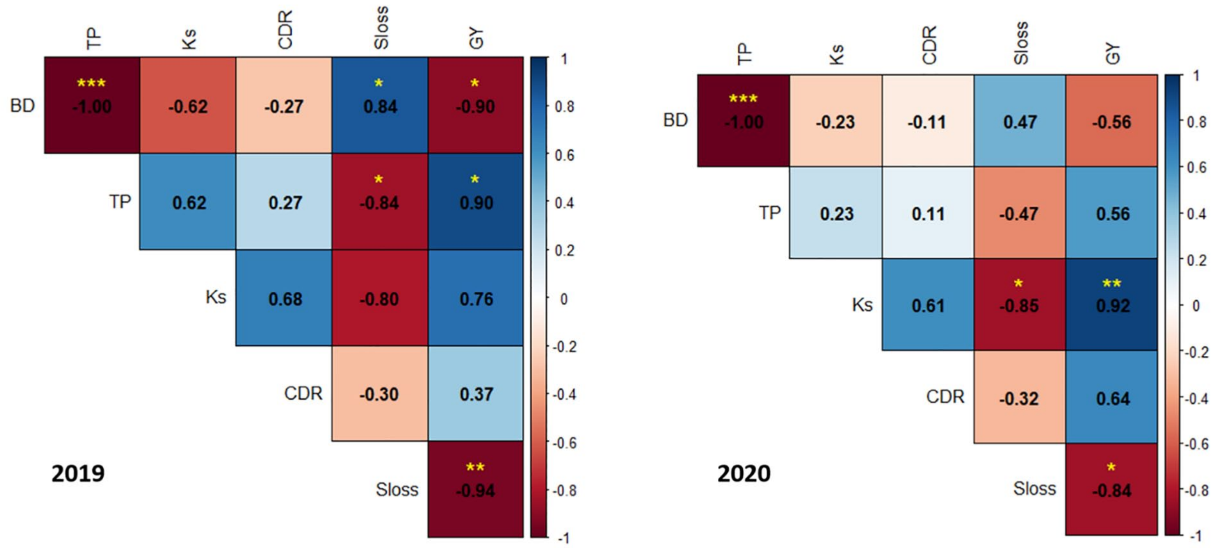

Figure 6. Pearson correlation coefficient matrix between soil loss, soil properties and maize yield in 2019 and 2020 ($n = 24$). *$p < .05$. **$p < .01$. Sloss; soil loss (Mg kg^{-1}), BD; bulk density (g cm^{-3}), TP; total porosity (%), Ks; saturated hydraulic conductivity (cm hr^{-1}), CDR; clay dispersion ratio (%), GY; grain yield (Mg ha^{-1}).

Table 5. Effect of Engineering Approaches and Poultry Manure on Maize Yield.

FACTORS	GRAIN YIELD (Mg ha^{-1}) 2019	2020
Engineering approaches (EA)		
Control	1.43	1.48
Furrow dike	1.54	1.64
Surface mat	1.60	2.12
Silt fencing	1.54	1.59
LSD ($p \leqslant .05$)	ns	0.28
Poultry manure (PM; t ha^{-1})		
0	1.55	1.58
20	1.56	1.85
LSD ($p \leqslant .05$)	ns	0.20
Interaction		
EA × PM	ns	ns

of arable lands in the study area to water erosion (Salako, 2003). The soil is slightly acidic with low concentration of total nitrogen and organic carbon. The available phosphorus concentration was in the medium range. The low nutrient composition is typical of the study area and suggest for sustainable management practices to improve soil quality (Busari & Salako, 2013). The agro-ecological transition from forest to savannah likely resulted in low soil vegetation cover and organic matter deposition, which could have contributed to the low chemical properties and easily predisposed the soil and environment to degradation (Amankwah et al., 2021; Oliveras & Malhi, 2016).

The amount of soil loss under surface mat was lower compared to other engineering approach, regardless of the manure application treatment. Geotextile soil cover protects soil surface from direct impact of raindrops, mitigating the erosion processes of detachment, transportation, and deposition of soil particles (Vaezi et al., 2017). The values obtained under surface mat (0.91–1.64 Mg ha^{-1} year^{-1}) were lower than the soil loss tolerance limit. Soil loss tolerance (T-limit) depicts the "maximum rate of annual soil loss that will permit plant productivity to be maintained economically and indefinitely" (Salako, 2003), and was estimated at 2 Mg ha^{-1} year^{-1} for tropical soils (Igwe, 1999; Lal, 1985). Our result corroborates the findings of Bhattacharyya et al. (2010) and Kalibová et al. (2016) and they recommended the use of geotextiles to control water erosion.

Furthermore, application of poultry manure improved soil conservation, which have been verified by previous studies (Abiven et al., 2009; De Melo et al., 2019; Qiang et al., 2024; Watts et al., 2023). Soil loss was reduced (with less positive soil pin values) from the time the poultry manure was incorporated to when the experiment was terminated. This aligns with the findings of Watts et al. (2023) as they reported the highest soil loss 1 week after manure application. Due to decomposition dynamics, the effectiveness of poultry manure in reducing soil loss is time-dependent as organic matter from manure requires time to be become incorporated into the soil (Abiven et al., 2009; Goldberg et al., 2020). This could have suggested the benefit of poultry manure in reducing soil loss in 2020 than 2019, coupled with the reapplication in the 2020 cropping season.

The improved soil physical properties under the engineering approach, particularly under surface mat as compared to control, could be attributed to the ability to maintain soil structure. The soil cover provided by the surface mat reduced soil disturbance from direct impact of rainfall that may cause splash erosion. The detached soil particle may induce soil sealing and compaction, which might be responsible for the higher soil bulk density and lower hydraulic properties obtained in this study. Silva et al. (2019) reported that the pore sealing and compaction effects resulting from soil exposure to rainfall lead to high runoff and soil loss resulting from low water penetration.

The low C/N ratio (1.09) of the poultry manure used in this study suggests higher mineralization of the manure than immobilization (Busari et al., 2008). This low carbon content in the poultry manure could have contributed to the low differences observed in soil physical properties. However, we observed a significant increase in hydraulic conductivity under poultry manure at 20 t ha^{-1} and in combination with the engineering approaches (Table 3 and Figure 5). This suggest the potential of poultry manure in improving soil physical attributes that will possibly increase water transmission properties and possibly minimize soil erosion. Moreover, previous study by Adeyemo et al. (2019) supports that poultry manure significantly reduce soil compaction, promote soil aggregation, improve water storage capacity, and increase soil pore distribution for better water transmutability (Adeyemo et al., 2019). Busari (2017) had established that a noticeable change in soil physical and hydraulic properties would be achieved with the application of 20 t ha^{-1} of poultry manure in combination with sustainable soil management practices.

We recorded a higher maize yield under the engineering approaches compared to the control, which was more evident under the surface mat. The application of geotextile soil cover can serve as a good water conservation practice to support maize yield and improve water use efficiency, which corroborates the findings of Jia et al. (2023). The sparse weed growth under the surface mat compared to other approaches (result not presented) could have contributed to the higher maize yield. Weed infestation has the potential to reduce maize yield by up to 50% (Landau et al., 2021) and can be controlled using geotextiles (Mzabri et al., 2021; Osadebe et al., 2016). Poultry manure is enriched with nutrients, particularly nitrogen and phosphorus, that can improve soil fertility and support maize growth and development (Adeyemo et al., 2019; Essilfie et al., 2024). These attributes could have contributed to the higher maize yield under 20 t ha^{-1} of poultry manure observed in this study. The substantial increase in maize yield observed in 2020 is probably associated with the re-application of poultry manure. Similarly, the negative correlation of maize yield with soil loss and bulk density confirms the high sensitivity of maize yield to soil degradation in the form of soil compaction and erosion (L. Zhang et al., 2021).

Conclusion

This study showed that surface mat approach improved maize yield, and reduced soil loss. Surface mat with the application of poultry manure at 20 t ha^{-1} reduced the rate of soil loss, improved soil physical properties, and sustained maize yield more than any other engineering approach. Due to the erratic weather conditions and increasing food insecurity across the globe, reports on soil degradation are pertinent. Therefore, these conservative methods involving the combination of simple and economically friendly management approaches could be good strategies to minimize soil degradation, improve the productivity of slopy lands, and boost farmers confidence to adopt.

Author Contributions

Olanrewaju Hameed Ologunde: Conceptualization, Validation, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing—original draft, and Writing—review & editing. Sodiq Dimeji Akanni: Conceptualization, Investigation, Data collection, Validation, Formal analysis, Data curation, and Writing—review & editing. Abdullahi Bamidele Olayemi: Methods, Investigation, Validation, and Writing—review & editing. Mutiu Abolanle Busari: Conceptualization, Methods, Validation, Supervision, Methodology, and Writing—review & editing.

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Data Availability

Data will be made available on request.

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