FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

SOIL AND WATER CONSERVATION PRACTICES: A TOOL FOR SUSTAINABLE FOOD SECURITY

BY:

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INAUGURAL LECTURE SERIES 115

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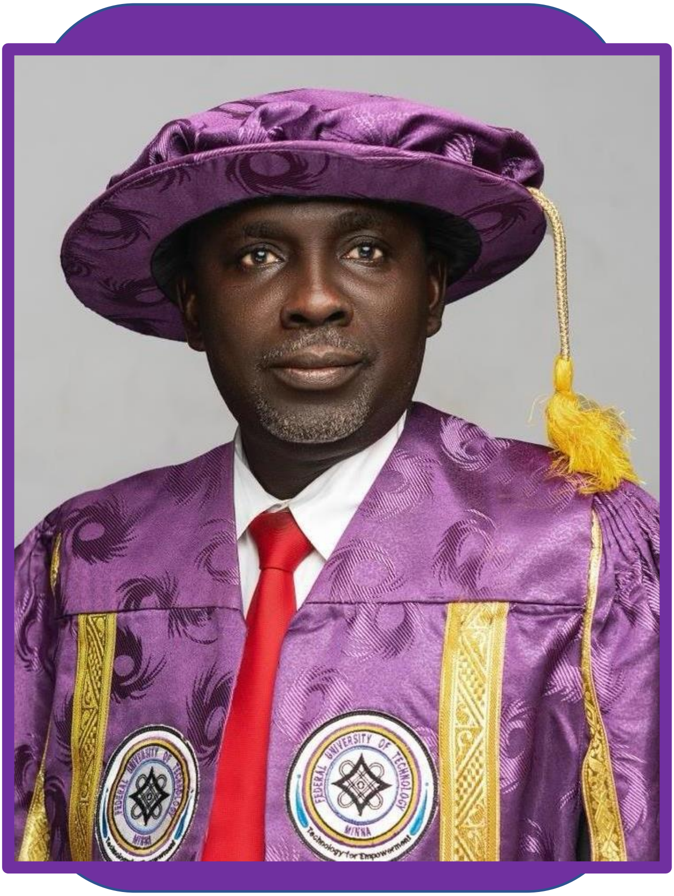

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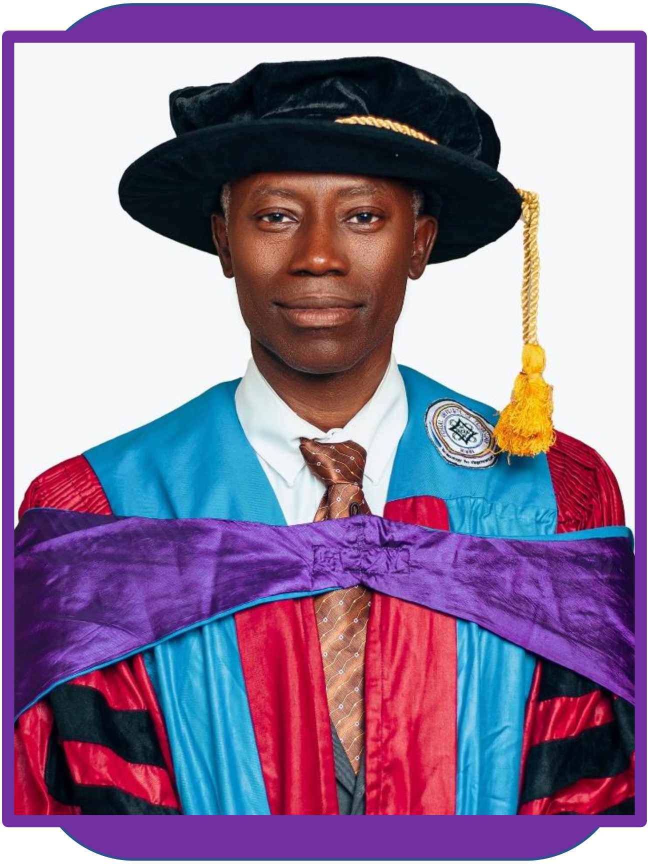

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PREAMBLE

Nigeria's lush fields and meandering rivers provide a magnificent tapestry of life and nourishment. Our country, abundant in natural resources and cultural diversity, has traditionally depended on the earth's bounty to support its people and foster economic prosperity. Our soils and waterways have supported generations, offering food, livelihoods, and a strong bond with the land, from the savannahs of the North to the lush rainforests of the South. The importance of soil and water conservation cannot be overstated, especially in light of Nigeria's current issues with an expanding population, shifting climatic patterns, and the constant threat of food insecurity. We must preserve, safeguard, and revitalise our natural resources to maintain agriculture's sustainability.

1.0 INTRODUCTION

Soil and water are crucial resources for the global agricultural system, providing food security, economic stability, and environmental sustainability (Adewumi *et al*., 2020). The history of agriculture dates back thousands of years, with early settlements along riverbanks where fertile soil and water resources allowed for crop cultivation. As populations expanded, humans began altering the landscape for farming, leading to the beginning of soil and water conservation practices. Ancient civilizations like Mesopotamians and Egyptians built elaborate irrigation systems to manage water resources efficiently for food production. The agricultural revolution in the 18th and 19th centuries led to mechanized farming and advances in crop breeding, leading to increased productivity but often unsustainable land use and environmental degradation (Kutigi *et al*., 2018). The Dust Bowl in the 1930s exemplifies the consequences of poor soil and water management, with widespread soil erosion and inadequate conservation practices leaving large farmland areas unusable.

1.1 INFILTRATION

Soil-water is crucial for plant root zone intake and irrigation plans. Infiltration, the first stage of water movement, solves runoff problems (Musa & Egharevba, 2009). It starts when rainfall hits the ground and continues until soil fills to field capacity. Understanding infiltration rate,

soil water content, and equation adaptability are essential for successful irrigation.
The mathematical theory of vertical infiltration is based upon the solution of the Richards equation as improved upon by Philip (1969), given as

$$\frac{d\theta}{dt} = \left[K(h)\left(\frac{dh}{dz} + 1\right)\right] \quad 1$$

Where θ is the volumetric moisture content (m^{-3} m^{-3}), t is the time (sec), z is the gravitational potential, K is the hydraulic conductivity (m/sec), h is the hydraulic potential (m), and K(h) is the hydraulic conductivity which is a function of h. The infiltration model was derived from Darcy's equation:

$$q = -k\Delta h \quad 2$$

Where q is the flow rate (m^3/s/m), and h is the hydraulic potential (m).

Kostiakov's Equation

The equation gives the functional relationship between infiltration, I, and time, t.

$$I = Mt^n + b \quad 3$$

Where I is the Infiltration rate (cm/hr.), the values of b, M, and n may be determined by the method of averages using the procedure suggested by Davis (1943). The value of b is determined by using equation 4:

$$b = \frac{I_1 I_3 - I_3^2}{I_1 + I_2 - 2I_3} \quad 4$$

The value of b would be subtracted from each value of I, and the logarithms of (I – b) and t would be taken. Rearranging equation 4:

$$I - b = Mt^n$$

Taking the logarithm of equation 4:

$$Log(I - b) = Log\ M + n\ Log\ t \quad 5$$

The logarithm of the above equation helps to express it in the form of a straight-line equation of the form $Y = Mx + C$ where M is the slope, X is the variable, and C is the intercept along the Y axis (Musa & Egharevba, 2009). Assuming the relationship between t and I is expressed by equation 5, it is not essential to determine the value of the rectifying factor, b, and the logarithm form of the expression will, therefore, take the form of

$$Log\ I = Log\ M + nLogt \tag{6}$$

Philip's Equation

The mathematical and physical analysis of the infiltration process developed by Philip (1957) separated the process into two components: those caused by sportive factors and those influenced by gravity. Philip's model takes the form of a power series, but in practice, an adequate description is given by the two-parameter equation (Musa & Egharevba, 2009).

$$i = st^{1/2} + At \tag{7}$$

Findings

Table 1 shows the R square values from curve fittings, showing that Kostiakov's equation best fits 99.35 % for fallowed land and 98.79 % for cultivated land. Philip's equation had a lower R square value (53.10 % for cultivated land and 55.22 % for fallowed land) due to its limitations in swelling homogenous soils and vertical flow. Table 2 shows the average infiltration rate for 12 weeks in fallowed and cultivated soils.

Table 1: R square values for three models

% R Square value	Horton's Model	Philip's Model	Kostiakov's Model
0.5	Nil	53.10 (Cultivated Land)	Nil
0.60	75.88 (Cultivated Land)	55.22 (Fallowed land)	Nil
0.70	75.69 (Fallowed Land)	Nil	Nil
0.80	Nil	Nil	98.79 (Cultivated Land)
0.90	Nil	Nil	99.35 (Fallowed Land)

Table 2: Average infiltration rates (cm/hr) for 12 weeks for the various land use practices.

Time (min.)	Fallowed Land		Cultivated Land	
	Cumulative water intake(cm)	Infiltration Rate (cm hr^{-1})	Cumulative water intake (cm)	Infiltration Rate (cm hr^{-1})
0	0	0	0	0
1	0.77	45.99	1.12	67.09
2	1.32	39.80	1.99	59.68
5	2.56	30.58	4.13	49.51
10	4.28	25.67	1.15	42.89
15	5.80	23.21	9.83	39.01
20	7.39	21.48	12.39	37.36
30	9.16	19.22	17.31	34.61
45	13.06	17.30	23.79	32.39
60	16.29	16.21	31.05	31.08
75	19.42	15.53	37.21	29.77
90	22.64	15.10	43.56	29.04
100	24.53	14.74	47.30	28.36
120	28.29	14.14	54.47	27.33

The study compared infiltration rates and cumulative water intake between cultivated and fallowed lands over 12 weeks to understand the impact of soil disturbance and rainfall on water penetration (Musa & Adeoye, 2010). In May, cultivated land had a higher infiltration rate of 32.28 cm hr^{-1} with a cumulative water intake of 64.57 cm, while fallowed land had an infiltration rate of 11.30 cm hr^{-1} and a cumulative water intake of 22.60 cm. This reduction in water intake rate is attributed to a two-day rain event between April and May. In June, cultivated land experienced a further decrease, while in July, fallowed land had an infiltration rate of 14.12 cm hr^{-1} and a cumulative water intake of 28.31 cm. These reductions in cultivated and fallowed lands signify the impact of intense rainfall during April and May (Okorafor et al., 2017). On average, cultivated land consistently exhibited a higher water intake rate than fallowed land, possibly due to undisturbed soil in the fallowed area or a potentially high-water table in the fallow region. Negative percentage errors were observed during the wet season for both fallowed and cultivated soils, indicating discrepancies between observed and model-predicted values.

Predicting Infiltration Rate

The study utilised chi-square/regression and least square methods to calculate expected infiltration rate data. Kostiakov's model showed negligible differences between calculated and observed data, making it closer to predicting infiltration rate than Philip and Horton's model. However, the calculated cumulative infiltration was negative, similar to previous studies in Minna, Niger State, and Samaru in Zaria (Musa & Egharevba, 2009).

Table 3: Estimated soil parameters for infiltration for 12 weeks

Land Use Practice	Estimated Soil Parameter (Kostiakov)	Estimated Soil Parameter (Philip's)	Estimated Soil Parameter (Horton's)
Cultivated Soil	M = 1.069 n = 0.821 b = 0.054	A = 25.811 S = 45.131	I_o = 67.09 I_c = 27.33 M = 0.006 Ø = 2.98
Fallowed Soil	M = 0.741 n = 0.760 b = 0.034	A = 12.259 S = 26.506	I_o = 45.99 I_c = 14.14 M = 0.0081 Ø = 2.98^{-3}

Table 4: Estimated soil parameters for infiltration for dry and wet seasons

Land Use Practice	Estimated Soil Parameter (Kostiakov)		Estimated Soil Parameter (Kostiakov)		Estimated Soil Parameter (Kostiakov)	
	Dry	Wet	Dry	Wet	Wet	Dry
Cultivated Soil	M = 1.2454	M = -1.3970	A = 6.6865	A = 4.0961	I_o = 79.50	I_o = 54.68
	n = 0.834	n = 0.8363	S = 11.074	S = 6.4691	I_c = 0.0057	I_c = 20.75
	b = 0.102	b = 1.9074			M = 0.0021	M = -0.0065
Fallowed Soil	M = 0.7269	M = -3.9057	A = 2.9456	A = 2.9456	I_o = 67.09	I_o = 42.98
	n = 0.7759	n = 1.1265	S = 4.2292	S = 3.8257	I_c = 27.33	I_c = 15.02

	b = 0.023	b = 0.0303		M = 0.006	M = -0.0072
				Ø = 2.98	Ø = -0.0026

The infiltration rates of the tested soil range between 5.80 - 46.20 cm/hr, which can become stable over time. Kostiakov's equation performed better than Philip's and Horton's equations for cultivated and fallowed soils. The equation best describes the irrigation farm of the Federal University of Technology, Minna, Niger State, Nigeria, as Y = 0.4881x + 1.2192 (Musa & Egharevba, 2009; Musa & Adoye, 2010). The graph of cumulative infiltration against elapsed time is given as Y = 0.5094x – 9.0431 for the same area. Infiltration tests performed during the dry season are preferable, as they are unlikely to reflect stable soil characteristics and the influence of antecedent soil water content on the measured infiltration capacity (Musa & Egharevba, 2009; Musa & Adeoye, 2010).

FUNCTIONS OF INFILTRATION

The research paper "Soil Grouping of the Federal University of Technology Minna, Main Campus Farm using Infiltration Rate" by Musa & Egharevba (2009) focuses on categorising soil properties at the main campus irrigation farm based on infiltration rates. The study, conducted in two phases, measured infiltration rates across soil layers and analyzed these rates to group the soil into different categories. The study found that the sandy loam soil layer had the highest infiltration rate, followed by the loamy sand layer, and the clayey layer had the lowest. This highlights the importance of infiltration rate knowledge in developing appropriate soil management practices for distinct soil types.

A subsequent study by Musa *et al*. (2012) investigated the impact of surface runoff on soil erosion and sediment yield in the Gidan Kwano area of Niger State, Nigeria. Field investigations revealed that land use and slope gradient significantly influenced surface runoff and sediment yield, with agricultural land on steep slopes exhibiting the highest sediment yield and forested areas the lowest. Soil properties, including

texture and organic matter content, played a crucial role in sediment yield.
Another study by Musa *et al*. (2012) aimed to reduce soil loss through surface runoff by developing an empirical hydrologic model to determine the Manning and Runoff Coefficient for selected soils at the permanent site of the Federal University of Technology, Minna, Nigeria. The study calculated the time of concentration for various soil types under different conditions using various equations.

Table 5: Various equations considered for the estimate of time of concentration

S/NO	Method/Equation	Equation in SI Unit
1	Kirpich	$T_c = 0.0078\frac{L^{0.77}}{S^{0.385}}$
2	Bransby Williams	$T_c = 21.3\frac{1}{5280A^{0.1}S^{0.2}}$
3	Soil Conservation Services (SCS)	$T_c = 0.00526L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.9} S^{-0.5}$
4	FAA	$T_c = \frac{1.8(1.1-C)L^{0.5}}{S^{033}}$
5	NRCS Time Lag	$T_L = \frac{2.587L^{0.8}\left(\frac{1000}{CN-9}\right)^{0.7}}{S^{0.5}}\ but\ T_c = \frac{T_L}{0.6}$

Table 6: Calculated time of concentration for various soil conditions using various equations.

S/No	Type of Soil	Soil Condition	Kirpich Equation (Mins)	Bransbey Williams Equation (Mins)	SCS Equation (Mins)	FAA Equation (Mins)	Time Lag Equation (Mins)
1	Sandy	Undisturbed	50	43.06	27	52.14	11.09
		Disturbed	50	43.06	26	51.33	10.77
2	Sandy Loam	Undisturbed	50	43.06	20	51.14	8.04
		Disturbed	50	43.06	23	5012	9.52
3	Clay	Undisturbed	50	43.06	14	49.01	5.78
		Disturbed	50	43.06	16	51.03	6.62
4	Loam	Undisturbed	50	43.06	16	51.03	11.09
		Disturbed	50	43.06	18	49.01	10.77

5	Sandy Clay	Undisturbed	50	43.06	20	51.34	8.04
		Disturbed	50	43.06	23	50.33	9.52

The developed model of $T_c = 0.938L^{0.878}\ n^{0.324}\ \theta^{0.222}\ S^{(-0.049)}\ i^{(-0.075)}$ was used to calculate n values for soil types and conditions. The model considers soil types when designing hydrologic models, improving flood forecasting and water resource management in the study area. The variations in Manning's roughness and runoff coefficient values highlight the importance of considering soil types. Compared to existing models, this model proved to be a better method for determining the Manning-Nigeria coefficient (Musa *et al*., 2012). Table 7 presents the n values using various calculated values of time of concentration for the mathematical model.

Table 7: *n* values using various calculated values of time of concentration for the developed mathematical model

S/No	Type of Soil	Soil Condition	SCS T_c	FAA T_c	Time Lag T_c
1	Sandy	Undisturbed	3.70	8.87	0.37
		Disturbed	3.48	8.73	0.33
2	Sandy Loam	Undisturbed	1.98	8.41	0.03
		Disturbed	2.69	8.26	0.14
3	Clay	Undisturbed	0.68	7.64	0.00
		Disturbed	1.11	8.17	0.00
4	Loam	Undisturbed	1.03	7.91	0.25
		Disturbed	1.42	7.66	0.22
5	Sandy Clay	Undisturbed	1.82	8.09	0.01
		Disturbed	2.70	8.41	0.15

Based on the findings, the developed empirical hydrologic model can effectively determine the Manning and Runoff Coefficient for the selected soils at the Federal University of Technology, Minna, Nigeria, Permanent Site. This model can be utilised for future planning and design purposes related to flood control, drainage systems, and water management in the study area. In another study, we employed hydrological modelling techniques to estimate stormwater runoff and sediment yield in the Upper Niger River Basin, with a focus on the Rural Development Authority farm site. The calibrated SCS-CN method, incorporating land cover data, yielded improved Curve Number and initial abstraction ratio values. Results showed significant improvements in model efficiency (34%) and predictive bias reduction (58.3%), highlighting the impact of slope gradients on runoff and sediment yield. Strong correlations were observed between slope, runoff, and sediment yield (R2 = 0.96, P < 0.01; R2 = 0.9935, P < 0.001). Effective management practices, such as contour cropping and strip cropping, significantly reduced sediment yield. This study contributes valuable insights into optimizing stormwater runoff and sediment yield estimation, informing evidence-based watershed management and conservation strategies in the Kainji Dam catchment.

1.2 SOIL EROSION

Soil erosion is a global threat causing soil nutrient depletion, soil quality degradation, soil structure destruction, and ecosystem disruption (Musa *et al*., 2021). This reduces productive land availability for cultivation, food sufficiency, and security in countries like Nigeria. Factors influencing soil loss and movement include soil nature, slope/topography, vegetation presence, and climatic conditions. Rainfall is the primary factor in soil loss and movement (Musa *et al*., 2021). Man's actions, such as agricultural encroachment, deforestation, urbanization, and land misuse, exacerbate the impact of soil erosion on the environment. Soil erosion causes decreased agricultural productivity, increased landslide activity, ecosystem disturbance, and contaminant diffusion (Okorafor *et al*., 2017; Deng *et al*., 2020).

Soil erosion occurs in three phenomena: detachment, transportation, and deposition, with rainfall creating the medium through which they all occur (Deng *et al*., 2020). Soil erodibility is a lumped or complex parameter that describes how soil is gradually detached during rainfall, surface runoff, or both actions (Idah *et al*., 2009). The characteristics of the rainstorm determine erodibility. Soil with a relatively low erodibility factor may show signs of severe erosion, while soil could be highly erodible and suffer little erosion. Soil erosion is a function of many factors, as stated in the universal soil loss equation (USLE), including rainfall factor (R), soil erodibility factor (K), slope length (LS), crop factor (C), and control practice factor (P) (Musa *et al*., 2012).

$$A = RKLSCP \qquad 8$$

In the Owerri West Local Government Area of Imo State, Nigeria, the removal of forest due to population growth has led to soil erosion due to rapid runoff from enlarged impervious surfaces like roofs, roads, and footpaths (Idah *et al*., 2008). This urbanization phenomenon is often exaggerated, with the human component being the primary cause of erosion. The erodibility indices of soils in some communities in Owerri West Local Government Area of Imo State show that Ohi has the most erodible soils, with a value of (0.044), followed by Obinze and Ihiagwe. The most erodible Ohi has the highest predicted soil losses of 9.462 $tons^{-1}$ ha^{-1} yr, followed by Amakohia-Ubi (8.602 $tons^{-1}$ ha^{-1} yr) and Orogwe (8.6 $tons^{-1}$ ha^{-1} yr). Obinze and Ihiagwa have the least predicted soil losses of 6.236 $tons^{-1}$ ha^{-1} yr each (Idah *et al*., 2008).

Table 8: Average erodibility index (K) of project locations and predicted soil losses for the various communities using Hudson's (1995) equation.

Location	Average K-Index	Soil Loss (tons/ha/yr)
Ndegwu	0.035	7.526
Orogwe	0.040	8.602
Amakohia Ubi	0.029	8.602
Obinze	0.032	6.881
Oforola	0.030	6.451
Avu	0.036	7.741
Umuguma	0.036	7.741
Emeabia	0.033	7.096
Eziobodo	0.029	6.236
Ihiagwa	0.034	7.311
Irete	0.036	7.741
Ohi	0.044	9.462
Okuku	0.037	7.958

The study analyzed the erodibility factors of soils in 15 communities in Owerri West Local Government Area, Imo State. Sandy soils were the most common, with high erodibility factors in Ohi, Orogwe, and Amakohia-Ubi due to their low cohesive force and high water

permeability rate. High clay content also had low erodibility factors due to higher binding and inter-binding forces.
The hydrometer test revealed that Ohi had the highest erodibility index of 0.044, followed by Orogwe and Amakohia-Ubi with 0.040. Minor erodibility indices were obtained in Obinze and Ihiagwe towns. The data from this study will help design and construct conservative structures to effectively counter erosion threats in these communities.
A similar study by Musa *et al*. (2017) examined the effect of soil physical properties on erodibility and infiltration parameters in selected areas of Gidan Kwano in Niger State. The study determined the soil structure, particle size distribution, moisture content, bulk density, infiltration rate, and soil erodibility.
The Bougocous hydrometer method showed that Plot B had a higher percentage of sand than Plot A, with a higher percentage of sand in each soil sample from Plot B ranging from 51% to 62%. Additionally, plot B had higher clay and silt contents, making it more suitable for crop production than plot B. Afolabi *et al*. (2014) found a very high percentage of sand in plot A, ranging from 68% to 76% and 74% to 79%, compared to the respective soil conditions.

Table 9: Soil particle sizes and textural classification results for selected areas

Plots	Samples	% Sand	% Silt	% Clay	Textural Classification
	1	51	35	14	Medium Loam
A	2	41	38	21	Medium Loam
	3	44	36	20	Medium Loam
	1	62	12	27	Sand Clay Loam
B	2	51	10	40	Sand Clay
	3	57	17	27	Sand Clay Loam

The study found that Plot B infiltrated faster than Plot A due to the dry soil particles. The shape, size, and stability of soil aggregates can affect rainwater absorbance and infiltration rates. Coarse-grained sandy soils have large spaces between grains, allowing water to infiltrate quickly. Soil infiltration rates decrease until a steady state is reached. Factors such as soil texture, structure, initial soil water content, pore size, soil matric potential, and vegetation also affect infiltration. The cumulative infiltration shows a rapid increase in water volume within a short time, gradually increasing to a nearly linear rate over time.

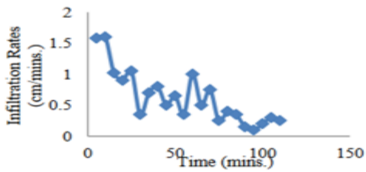

Figure 1: Infiltration Rate graph of Plot A

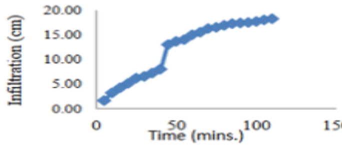

Figure 2: Cumulative Infiltration of Plot A

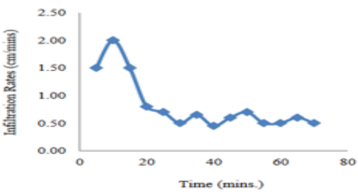

Figure 3: Infiltration Rate Graph of Plot B

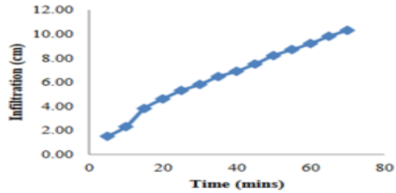

Figure 4: Cumulative Infiltration of Plot B.

The highest value of bulk density and particle density was found in Plot A, as observed from Table 3, which ranges between 1.36 gcm^{-1} and 1.71 gcm^{-1}, while Plot B's ranged between 1.40 gcm^{-1} and 1.45 gcm^{-1}. This is similar to the works of Musa & Egharevba (2009) and Musa *et al*. (2013).

Researchers have found that soil moisture movement rate impacts nutrient solubility and water distribution. Soil storage capacity depends on soil porosity, as water moves faster through macro-pores on sandy soils than clay soil. High porosity in sandy soil, like Plot B, makes it difficult to store water due to faster water movement through macro-pores.

Table 10: Soil Aggregates Results of Plot A

Sample	Depth (cm)	Particle Size			Bd(gcm^{-1})	Pd (gcm^{-1})	P (%)	OC (%)	OM (%)
		% Sand	% Silt	% Clay					
1	0-30	59	28	13	1.45	1.56	7.05	2.50	4.30
	30-60	43	42	15	1.26	2.94	57.10	2.10	3.60
2	0-30	42	39	19	1.80	2.80	35.70	2.70	4.60
	30-60	40	38	22	1.61	2.90	44.50	2.10	3.60
3	0-30	48	33	19	1.52	1.99	23.60	2.60	4.50
	30-60	40	39	21	1.44	3.10	53.50	2.00	3.40

Bd is Bulk Density, Pd is Particle Density, P is Porosity, OC is Organic Carbon, and OM is Organic Matter

Table 11: Soil Aggregates Results of Plot B

Sample	Depth (cm)	Particle Size			Bd(gcm^{-1})	Pd (gcm^{-1})	P (%)	OC (%)	OM (%)
		% Sand	% Silt	% Clay					
1	0-30	57	20	23	1.39	1.70	18.20	1.80	3.10
	30-60	66	3	31	1.51	1.89	20.10	2.80	4.80
2	0-30	53	9	38	1.40	1.78	21.30	2.30	4.00
	30-60	48	11	41	1.43	1.80	20.60	2.00	3.40
3	0-30	48	30	22	1.28	1.82	29.70	1.80	3.10
	30-60	42	25	33	1.45	1.91	24.10	1.50	2.60

Bd is Bulk Density, Pd is Particle Density, P is Porosity, OC is Organic Carbon, and OM is Organic Matter

Table 12 presents the erodibility index of the selected plots. Soil erodibility factor (K) is a quantitative description of the inherent erodibility of a particular soil as it measures the susceptibility of the soil particles to detachment and transportability by rainfall and runoff. This factor reflects that different soils erode at different rates when the other factors that affect erosion are the same (Lin *et al*., 2023). The determined erodibility indexes of the various plots were highly negative, meaning that the soil is highly erodible, compared to plot B's, much higher than plot A's.

Table 12: Erodibility Index for the various Plots

Plots	Sample	Depth (cm)	Erodibility Index K)
	1	0-60	-121.46
A	2	0-60	-126.83
	3	0-60	-131.34
	1	0-60	-145.24
B	2	0-60	-815.99
	3	0-60	-108.51

The study examined the physical properties of soil in selected areas of the Federal University of Technology, Minna, Gidan Kwanu Campus. Results showed that the soil type in plots A and B was medium loam and sandy clay loam, making them susceptible to erosion due to slow infiltration. Plot B had a higher infiltration rate than Plot A, and the sample with the least moisture content was in Plot A. This poor infiltration rate led to water ponding, depressions, and surface runoff, carrying away fine soil particles.

A more robust study was conducted to determine soil erodibility indices for selected soils in Nigeria's southern Guinea Savanna Ecological zone under rainfed agricultural practice. The average moisture content of plots A, B, C, D, and E ranged from 7.950 to 9.067 %. The results showed that plot B permeates more than plots A, C, D, and E. The permeability rate became stable at 45 minutes for plots A, B, and D, while plots C and E remained stable at 33 and 48 minutes.

Table 13: Soil Moisture Content of Plots A, B, C, D and E.

S/N	Samples	Soil Depth (cm)	Weight of container + Soil Sample (g) W_2	Weight after oven-dry (g) W_3	Moisture Content %	Average Moisture Content %
1		0-10	150.360	140.041	9.033	
2	A	10-20	150.374	139.918	9.144	9.067
3		20-30	150.253	139.934	9.025	
4		0-10	150.939	140.897	8.598	
5	B	10-20	150.695	140.678	8.705	8.507
6		20-30	150.294	140.789	8.217	
7		0-10	150.450	140.567	8.574	
8	C	10-20	150.630	140.894	8.415	8.275
9		20-30	150.821	141.698	7.837	
10		0-10	150.197	140.689	8.232	
11	D	10-20	149.852	140.053	7.673	7.950
12		20-30	150.198	140.987	7.946	
13		0-10	150.764	140.673	8.732	
14	E	10-20	150.675	140.251	9.050	8.926
15		20-30	150.568	140.238	8.997	

Table 14: Permeability rate of soil at plot A

S/N	Time Elapsed (Min)	Initial Reading (cm)	Water Intake (cm)	Cumulative Water intake	Permeability (cm/hr)
1	0	15.00	-	-	-
2	3	13.04	1.96	1.96	39.20
3	6	10.82	2.22	4.18	22.20
4	9	9.90	0.92	5.10	6.13
5	12	8.90	1.00	6.10	5.00
6	15	7.85	1.05	7.15	4.20
7	18	7.50	0.35	7.50	1.17
8	21	7.01	0.49	7.99	1.40
9	24	6.80	0.21	8.20	0.53
10	30	5.40	1.40	9.60	2.80
11	33	5.09	0.31	9.91	0.62
12	36	4.85	0.24	10.15	0.44
13	39	4.50	0.35	10.50	0.58
14	42	3.50	1.00	11.50	1.54
15	45	3.10	0.40	11.90	0.57
16	48	2.89	0.21	12.11	0.28
17	51	2.62	0.27	12.38	0.34
18	54	2.41	0.21	12.59	0.25
19	57	2.00	0.41	13.00	0.46
20	60	1.90	0.10	13.10	0.11

Table 15: Infiltration Rate of Soils at Plot B

S/N	Time Elapsed (Min)	Initial Reading (cm)	Water Intake (cm)	Cumulative Water intake	Permeability (cm/hr)
1	0	15.00	-	-	-
2	3	12.95	2.05	2.05	41.00
3	6	10.50	2.45	4.50	24.50
4	9	9.80	0.70	5.20	4.67
5	12	8.50	1.30	6.50	6.50
6	15	7.01	1.49	7.99	5.96
7	18	6.22	0.79	8.78	2.63
8	21	5.60	0.62	9.40	1.77
9	24	4.90	0.70	10.10	1.75
10	30	4.35	0.55	10.65	1.10
11	33	3.92	0.43	11.08	0.95
12	36	3.40	0.52	11.60	0.95
13	39	3.00	0.40	12.00	0.67
14	42	2.79	0.21	12.21	0.33
15	45	2.10	0.69	12.90	0.99
16	48	1.60	0.50	13.40	0.67
17	51	1.42	0.18	13.58	0.23
18	54	1.02	0.40	13.98	0.47
19	57	0.50	0.52	14.50	0.58
20	60	0.41	0.09	14.59	0.09

Table 16: Permeability Rate of Soil at Plot C

S/N	Time Elapsed (Min)	Initial Reading (cm)	Water Intake (cm)	Cumulative Water intake	Permeability (cm hr^{-1})
1	0	15.00	-	-	-
2	3	13.09	1.91	1.91	38.2
3	6	11.20	1.89	3.80	18.9
4	9	9.22	1.98	5.78	13.2
5	12	8.89	0.33	6.11	1.65
6	15	7.01	1.88	7.99	7.52
7	18	6.60	0.41	8.40	1.37
8	21	6.01	0.59	8.99	1.69
9	24	5.60	0.41	9.40	1.03
10	30	4.97	0.63	10.03	1.26
11	33	4.01	0.96	10.99	1.75
12	36	4.00	0.01	11.00	0.02
13	39	3.35	0.65	11.65	1.00
14	42	3.02	0.33	11.98	0.47
15	45	2.77	0.25	12.23	0.33
16	48	2.06	0.71	12.94	0.89

17	51	2.00	0.06	13.00	0.07
18	54	1.08	0.92	13.92	1.02
19	57	0.51	0.57	14.49	0.60
20	60	0.44	0.07	14.56	0.07

Table 17: Permeability rate of soil at plot D

S/N	Time Elapsed (Min)	Initial Reading (cm)	Water Intake (cm)	Cumulative Water intake	Permeability (cm/hr)
1	0	15.00	-	-	-
2	3	11.98	3.11	3.11	62.2
3	6	11.00	0.89	4.00	8.90
4	9	10.28	0.72	4.72	4.80
5	12	10.00	0.28	5.00	1.40
6	15	9.46	0.54	5.54	2.16
7	18	9.04	0.42	5.96	1.40
8	21	8.54	0.50	6.46	1.43
9	24	7.68	0.86	7.32	2.15
10	30	7.01	0.67	7.99	1.34
11	33	7.00	0.01	8.00	0.02
12	36	6.08	0.92	8.92	1.53
13	39	5.96	0.12	9.04	0.18
14	42	4.24	1.72	10.76	2.46
15	45	4.10	0.14	10.90	0.19
16	48	3.85	0.25	11.15	0.31
17	51	2.66	1.19	12.34	1.40
18	54	2.05	0.61	12.95	0.68
19	57	1.01	1.04	13.99	1.09
20	60	0.05	0.96	14.95	0.96

Table 18: Permeability Rate of Soil at Plot E

S/N	Time Elapsed (Min)	Initial Reading (cm)	Water Intake (cm)	Cumulative Water intake	Permeability (cm/hr)
1	0	15.00	-	-	-
2	3	13.82	1.18	1.18	23.6
3	6	11.26	2.56	3.74	25.6
4	9	10.79	0.47	4.21	3.13
5	12	9.86	0.93	5.14	4.65
6	15	8.83	1.03	6.17	4.12
7	18	7.79	1.04	7.21	3.47
8	21	6.52	1.27	8.48	3.63
9	24	6.01	0.51	8.99	1.28

10	30	5.66	0.34	9.34	0.68
11	33	5.03	0.63	9.97	1.15
12	36	4.68	0.35	10.32	0.58
13	39	4.35	0.33	10.65	0.51
14	42	3.92	0.43	11.08	0.61
15	45	3.00	0.92	12.00	1.23
16	48	2.80	0.20	12.20	0.25
17	51	2.00	0.80	13.00	0.94
18	54	1.56	0.44	13.44	0.49
19	57	1.07	0.49	13.93	0.52
20	60	0.99	0.08	14.01	0.08

Table 19: Soil Particle Size and Textural Classification result of the study areas

Plots	Samples	Depth (cm)	Particle Size % Sand	% Silt	% Clay	Textural Class
	1	0 - 10	81.24	10.56	8.20	Loamy Sand
A	2	10-20	79.13	11.96	8.91	Loamy Sand
	3	20 - 30	74.53	14.98	10.49	Sandy Loam
	1	0 - 10	78.39	13.24	8.37	Sandy Loam
B	2	10-20	75.96	13.98	10.06	Sandy Loam
	3	20 - 30	73.97	15.99	10.04	Sandy Loam
	1	0 - 10	82.98	9.26	7.76	Loamy Sand
C	2	10-20	78.98	11.37	9.65	Sandy Loam
	3	20 - 30	75.77	13.79	10.43	Sandy Loam
	1	0 - 10	80.44	11.32	8.24	Loamy Sand
D	2	10-20	77.88	12.57	9.55	Sandy Loam
	3	20 - 30	74.87	16.55	8.59	Loamy Sand
	1	0 - 10	83.09	9.56	7.35	Loamy Sand
E	2	10-20	78.90	12.98	8.12	Loamy Sand
	3	20 - 30	74.98	15.70	9.32	Loamy Sand

The study examined soil permeability and its relationship with soil dryness, permeability, and erosion susceptibility. The water movement rate within the soils was rapid, indicating soil dryness. Soil permeability could be related to the nature of shrubs and grasses, as roots tend to create pore spaces within the soil. The topsoil of plot B was observed to be drier than other plots of the study area, as observed from the water intake rate (Musa *et al*., 2021).

Soil permeability depends on several factors, such as soil texture, pore size, soil structure, soil metric potential, initial soil water content, and soil

vegetation (Eze *et al*., 2018). The moisture movement rate affects soil nutrient stability and water distribution (Musa *et al*., 2011). The ability of soil to store water depends on the soil pore spaces, as water moves faster through macro-pores (sandy soils) than micro-pores (clay soil).
Soil organic matter (SOM) varied greatly, ranging from 3.95 to 5.00 % for the five study areas (Dada *et al*., 2020). Most of the study areas were loamy, sandy soils that retain water more than other soil particles. The Bougocous hydrometer method showed that plot B had the highest percentage of sand content compared to the different plots of the study area.
The soil aggregate results indicated that the highest bulk density was observed at plot A, indicating the presence of many farming activities (Adesiji *et al*., 2018). The erodibility index of selected study areas eroded at different rates when other factors affecting erosion were kept constant (Dada *et al*., 2019). The study found that the soil permeability factor (K) was negative, indicating that the soil is highly not erodible.

2.0 Irrigation

Food security and stability worldwide rely on managing natural resources (Maja & Ayano, 2021). However, due to the depletion of water resources and population growth, irrigated areas per capita are declining, producing 40 % or less of the food supply. Nigeria, with abundant natural resources and arable lands, faces neglect from farmers due to infrastructural decay. Fadama, a term for low-lying areas susceptible to seasonal flooding, is often used for small-scale irrigation farming. Traditional schemes for rice and other grain crops have existed since pre-colonial times. The interest in developing irrigation agriculture is global, and farmers are controlling the shift to small-scale schemes due to the sustainability of large-scale schemes. Farmers control the change to small-scale irrigation due to the sustainability of large-scale schemes.

Findings

The study in Zukuchi aimed to improve irrigation activities in north-central Nigeria by providing a small-scale irrigation structure for farmers during the dry season (Ogbonnaya & Musa, 2010). A two-canal structure was designed with a discharge capacity of 0.42 $m^3\ s^{-1}$ to cover an irrigatable area of 5 ha of rice for each canal. However, constant water wastage was discovered due to a lack of control measures. Musa *et al*. (2010) developed software to control water delivery to the field using computer technology, but this technology is limited to areas with limited land availability and owner involvement.

Another study examined the use of tube wells for irrigating an average land mass of 5 hectares, which a single farmer could handle (Mustapha & Musa, 2008). The Blaney-Morinal Nigeria Empirical formula determined the crop's evapotranspirative water requirement. The results showed that potential evapotranspiration was relatively high during the months when irrigation practices were carried out in north-central Nigeria (Mustapha & Musa, 2008). The water requirement for the first four months of the dry spell was calculated to be 8.28 X 10^{-4} $m^{-3}s$, 1.15 X 10^{-3} $m^{-3}s$, 2.64 X 10^{-4} $m^{-3}s$, and 1.23 X 10^{-3} $m^{-3}s$. The study showed that with little water from boreholes, tubewells, and washbores, it is possible to irrigate large farm areas, provided the soil retains some water for crop growth. In addition, the study examined wastewater from the environment and its sanitary conditions for irrigation in gardens and orchards (Adeoye *et al*., 2012).


Plate 1


Plate 2


Plate 3

Plate 1 contains the intestinal contents of slaughtered animals being washed into the open channel; Plate 2 is the dunghill formed by intestinal contents, and Plate 3 is the stream that receives all the wash water from the abattoir.

The study found that water samples from various sources, including a stream path, hand-dugged well, and borehole, was clear, odourless, and tasteless (Adeoye *et al*., 2012). However, the pond samples at P0 and P10 were rough due to high suspended and dissolved solids levels. The pH ranged from 6.5 to 8.3, which is within acceptable limits. The higher iron value is believed to be due to animal blood washed into the water, possibly from leachates. The high total solids at P0 and P10 are likely from abattoir wastes, such as bones, tissues, intestinal contents, and wool. The high manganese level in all samples is not attributed to abattoir waste but could be due to underground pollution from the high concentration of mineral salts due to the geological nature of the aquifer's bedrock.

Table 20: Physico-chemical Values of the water samples

Parameter	P0	P10	P20	P30	HD1	BH1	WHO 2006
pH	6.57	6.50	6.75	7.20	8.00	8.30	6.5-8.5
Temperature (^0C)	36.40	33.90	26.20	26.30	27.00	27.51	Nil
Sodium (mgL^{-1})	43.00	33.00	48.10	47.20	51.00	30.53	Nil
Calcium (mgL^{-1})	140.90	70.30	131.15	136.00	150.90	221.12	75-200
Potassium (mgL^{-1})	125.00	74.80	74.88	75.00	74.88	31.12	Nil
Zinc (mgL^{-1})	0.05	0.02	0.12	0.99	0.67	16.71	5 - 15
Iron (mgL^{-1})	3.99	2.74	1.36	2.46	2.72	2.68	0.10-1.00
Copper (mgL^{-1})	0.31	0.63	0.11	0.14	0.33	0.43	0.05-0.50
Manganese (mgL^{-1})	0.45	2.11	2.63	2.90	3.31	3.73	0.05-0.50
Total Solid (mgL^{-1})	2080.00	1680.00	750.00	600.00	430.00	302.10	500-1500
Total Chloride (mgL^{-1})	250.17	141.75	102.44	104.20	99.30	115.40	200-250
Total Hardness (mgL^{-1})	361.30	135.89	162.90	166.40	179.00	175.00	100-500

Table 21: Bacteriological Assessment of the water samples

Parameter	P0	P10	P20	P30	HD1	BH1
Feacal Coliform ($cfumL^{-1}$)	189.20	120.00	86.40	89.90	12.00	Nil
Streptococcus feacalis ($cfumL^{-1}$)	120.40	89.20	83.40	60.30	11.40	Nil
Echerichia coli ($cfumL^{-1}$)	127.00	78.60	50.50	43.50	13.30	Nil
Total Plate Count ($cfumL^{-1}$)	170.70	145.90	68.10	72.40	1.56	0.91
Biochemical Oxygen Demand (mgL^{-1})	250.30	221.40	158.00	111.00	23.00	2.50
Dissolved Oxygen (mgL^{-1})	2.90	2.90	2.40	2.60	3.10	3.50

Another study examined the soil salinity and irrigation water quality in Chanchaga Irrigation Scheme I, Minna, Niger State. The mean concentration of exchangeable soil bases was 14.82, 40.0, 58.65, and 8.40 ($mg L^{-1}$) in the irrigated plot, compared to 6.87, 20.00, 37.44, and 1.46 in the control plot. The highest sodium concentration was observed in the irrigated plot, while magnesium had the lowest concentration. The concentrations of Ca^{2+} and Na^{+} were slightly different between the irrigated and control plots.

Table 22: Mean concentration of soil Exchangeable Bases in Chanchaga Irrigation Scheme I

Soil Exchangeable Bases	Irrigated Plot	Control Plot
K^{+} (mgL^{-1})	14.82	6.87
Ca^{2+} (mgL^{-1})	40.00	20.00
Na^{+} (mgL^{-1})	58.65	37.44
Mg^{2+} (mgL^{-1})	8.40	1.46

The study analysed soil pH, EC, SAR, and ESP values for the Chanchaga irrigation scheme (Kuti *et al*., 2018). The irrigated plot had higher values, indicating alkaline soil, while the control plot had acidic soil. The irrigated plot had higher electrical conductivity and sodium absorption ratio values but higher exchangeable sodium percentages. The irrigated plot had lower ESP due to its distance from the river, causing poor plant growth. However, the irrigated plot had low salt levels (0-2) and sodic soil, with minimal risk of plant injury. The study also tested equality variances between SAR, pH, temperature, and other exchangeable bases. The SAR, pH, and other exchangeable bases showed no significance level. At the same time, the chloride had a value of less than 0.10, indicating a significant difference between the irrigated and control plots of Chanchaga irrigation scheme I. Table 22 shows the Mean values of soil pH, EC, SAR and ESP for the Chanchaga irrigation scheme1, while Table 23 tests equality variances between SAR, pH, temperature, and other exchangeable bases.

Table 23: Test for equality variance between SAR and exchangeable bases

Attributes	Levene's Test for Equality of Variances				
	F	Significance	T	Df	Significance (2-Tailed)
pH	3.734	0.125	4.789	4	0.009
SAR	3.208	0.148	123.916	4	0.000
Na	0.800	0.422	1642.920	4	0.000
K	2.462	0.192	135.024	4	0.000
Mg	0.000	1.000	849.973	4	0.000
Ca	3.455	0.137	34.525	4	0.000
ESP	3.734	0.125	-66.532	4	0.000
EC	0.800	0.422	0.000	4	1.000
Chloride	8.000	0.047	287.182	4	0.000

The physiochemical properties of irrigation water in Chanchaga irrigation scheme I, including Ca^{2+}, Mg^{2+}, EC, SAR, Na^{+}, temperature, K^{+}, and ESP, are within the limits of FAO (1994) as presented in Table 23, except for electrical conductivity, potassium, and ESP, which have higher concentrations. The conductivity (0.163 dS m^{-1}) was higher in the river than FAO (1994) limits, indicating a sodic soil. The pH values show alkaline water, while the potassium concentration is higher than FAO (1994). This is a strong indication of the high population level in Nigeria. Such polluted water is used for irrigation, transferring high chemical contents into plants that humans and animals consume.

The physical and chemical properties of the Maikunkele stream for irrigation purposes were examined using the Water Quality Index (Musa *et al*., 2017). The mean temperature ranged between 29.5 ^{0}C and 30.4 ^{0}C for the five study locations, with temperature variations not statistically significant at the 5 % level. The pH values showed a slightly acidic and slightly basic stream, with electrical conductivity falling within the maximum permissible limit of 300 µscm^{-1} allowed for drinking water. The highest electrical conductivity was observed during the second month (February).

The lowest dissolved oxygen (DO) value was recorded in March due to a one-time rainfall in the study area, which diluted wastewater from neighbouring communities. The stream's biochemical oxygen demand (BOD) ranged between 2.0 and 7.0 mg L^{-1}, indicating chemical pollution during the dry season (Musa *et al*., 2017). All study points had high BOD values, exceeding the recommended WHO (2009) standard value of 5.0 mg L^{-1}, resulting in decreased dissolved oxygen levels. Total hardness (TH) ranged from 49 to 153 mg L^{-1}, within the WHO (2009) standard. Each sample's Water Quality Index (WQI) was analysed using the weighted arithmetic index for various physiochemical parameters. The results showed that the suitability of the water samples used for irrigation within the study area was calculated using the WQI formula, and the results obtained were ranked as presented in Table 4.

Kuti *et al*. (2019) investigated the Effect of Different Riser Heights on Sprinkler irrigation performance under constant operating pressure. Results showed losses ranging from 5.22 % to 10.2 %, consistent with Okasha and Pibars (2016). The study introduced uniformity and distribution coefficients for the sprinkler irrigation system, with coefficients at 1.5 m, 2.0 m, 3.0 m, and 4.0 m showing 85 %/78 % and 72 %/70 %, respectively. A riser height of 2.0 m exhibits the highest CU (89 %) and DU (85 %), while 1.5 m has the lowest (70 %/61 %).

Irrigation plays a vital role in increasing crop yields, and this study evaluated different irrigation methods based on the parametric evaluation method for the Chanchaga irrigation scheme, Minna.

Table 24: Descriptive Statistics of water quality parameter of investigated water samples

Station	Statistical Tool	Temp (0C)	pH	Cond	DO (mg L^{-1})	BOD (mg L^{-1})	COD (mgL^{-1})	TH (mgL^{-1})	Alkali (mg L^{-1})	NO3 (mg L^{-1})	PO3 (mg L^{-1})	Na (mg L^{-1})	K (mg L^{-1})	Mg (mg L^{-1})	Ca (mg L-1)	Mn (mg L^{-1})	Cu (mg L^{-1})	Zn (mg L^{-1})	Fe (mg L^{-1})
A	Mean	29.50	6.50	22.50	7.50	4.00	202.93	98.00	64.00	0.15	0.09	3.87	4.22	25.30	40.58	0.04	0.01	0.08	1.11
	Maximum	30.00	7.18	258.00	8.00	5.00	401.00	115.00	78.00	0.18	0.12	4.90	6.74	29.00	47.26	0.05	0.01	0.13	1.33
	Minimum	29.00	5.95	186.00	7.00	3.00	4.86	81.00	50.00	0.12	0.06	2.83	1.70	21.40	33.90	0.03	0.00	0.03	0.88
	SD	0.57	0.50	29.68	0.50	0.95	197.68	16.54	11.88	0.02	0.02	2.85	2.24	3.83	6.56	0.01	0.01	0.04	0.18
B	Mean	30.50	6.51	241.50	8.00	3.50	5.15	103.00	55.00	0.13	0.06	3.77	3.41	2.70	42.75	0.03	0.00	0.10	0.93
	Maximum	32.00	6.74	274.00	8.00	5.00	6.26	138.00	84.00	0.15	0.08	4.33	6.36	32.40	56.18	0.06	0.00	0.17	1.48
	Minimum	29.00	6.28	209.00	8.00	2.00	4.03	68.00	26.00	0.11	0.03	3.20	1.28	16.80	29.33	0.01	0.00	0.03	0.19
	SD	1.09	0.18	26.90	0.00	1.09	0.79	29.64	22.00	0.01	0.02	0.46	2.21	7.31	11.69	0.02	0.00	0.05	0.49
C	Mean	30.50	6.72	208.10	9.00	4.50	5.66	107.50	62.00	0.10	0.06	4.39	3.15	2.37	3.98	0.03	0.01	0.10	0.97
	Maximum	31.00	6.80	242.00	12.00	7.00	7.97	153.00	96.00	0.11	0.09	5.36	6.03	34.70	59.75	0.05	0.02	0.17	1.40
	Minimum	30.00	6.40	174.00	6.00	2.00	3.35	62.00	28.00	0.08	0.03	3.41	1.78	14.90	24.90	0.02	0.00	0.07	0.24
	SD	0.54	0.17	27.89	3.28	2.30	1.99	36.00	27.57	0.01	0.02	0.81	1.69	7.77	13.35	0.01	0.01	0.03	0.44
D	Mean	30.00	6.79	199.50	9.00	5.00	6.20	84.00	49.00	0.13	0.05	3.89	3.56	21.65	34.84	0.02	0.01	0.07	1.28
	Maximum	32.00	7.25	223.00	10.00	6.00	7.28	120.00	76.00	0.16	0.06	4.88	5.22	31.20	48.60	0.01	0.01	0.12	1.36
	Minimum	28.00	6.32	176.00	8.00	4.00	5.11	49.00	22.00	0.09	0.03	2.90	1.90	12.10	21.08	0.03	0.00	0.01	1.19

	SD	1.14	0.32	18.52	1.09	0.83	0.87	26.74	21.81	0.03	0.01	0.70	1.38	7.47	10.57	0.04	0.00	0.03	0.44
	Mean	30.00	6.65	233.50	8.00	3.50	4.94	100.00	58.50	0.10	0.07	4.50	3.78	24.55	41.34	0.02	0.04	0.50	0.65
E	Maximum	32.00	6.90	258.00	10.00	4.00	5.96	144.00	88.00	0.14	0.09	5.61	5.35	35.20	58.58	0.01	0.07	0.11	1.16
	Minimum	28.00	6.40	209.00	6.00	3.00	3.91	56.00	29.00	0.06	0.05	3.39	2.20	13.90	24.10	0.02	0.00	0.88	0.13
	SD	1.48	0.17	18.88	2.00	0.54	0.93	38.44	28.50	0.03	0.01	0.83	1.20	9.31	15.37	0.05	0.03	0.02	0.42

Table 25: Calculation of water quality Index for the various sample points

Station	Statistical Tool	Temp (0C)	pH	Cond	DO (mg L^{-1})	BOD (mg L^{-1})	COD (mgL^{-1})	TH (mgL^{-1})	Alkali (mgL^{-1})	NO3 (mg L^{-1})	PO3 (mg L^{-1})	Na (mgL^{-1})	K (mgL^{-1})	Mg (mgL^{-1})	Ca (mgL-1)	Mn (mgL^{-1})	Cu (mgL^{-1})	Zn (mgL^{-1})	Fe (mgL^{-1})
	Mean	29.50	6.50	22.50	7.50	4.00	202.93	98.00	64.00	0.15	0.09	3.87	4.22	25.30	40.58	0.04	0.01	0.08	1.11
A	Maximum	30.00	7.18	258.00	8.00	5.00	401.00	115.00	78.00	0.18	0.12	4.90	6.74	29.00	47.26	0.05	0.01	0.13	1.33
	Minimum	29.00	5.95	186.00	7.00	3.00	4.86	81.00	50.00	0.12	0.06	2.83	1.70	21.40	33.90	0.03	0.00	0.03	0.88
	SD	0.57	0.50	29.68	0.50	0.95	197.68	16.54	11.88	0.02	0.02	2.85	2.24	3.83	6.56	0.01	0.01	0.04	0.18
	Mean	30.50	6.51	241.50	8.00	3.50	5.15	103.00	55.00	0.13	0.06	3.77	3.41	2.70	42.75	0.03	0.00	0.10	0.93
B	Maximum	32.00	6.74	274.00	8.00	5.00	6.26	138.00	84.00	0.15	0.08	4.33	6.36	32.40	56.18	0.06	0.00	0.17	1.48
	Minimum	29.00	6.28	209.00	8.00	2.00	4.03	68.00	26.00	0.11	0.03	3.20	1.28	16.80	29.33	0.01	0.00	0.03	0.19
	SD	1.09	0.18	26.90	0.00	1.09	0.79	29.64	22.00	0.01	0.02	0.46	2.21	7.31	11.69	0.02	0.00	0.05	0.49
C	Mean	30.50	6.72	208.10	9.00	4.50	5.66	107.50	62.00	0.10	0.06	4.39	3.15	2.37	3.98	0.03	0.01	0.10	0.97

	Maximum	31.00	6.80	242.00	12.00	7.00	7.97	153.00	96.00	0.11	0.09	5.36	6.03	34.70	59.75	0.05	0.02	0.17	1.40
	Minimum	30.00	6.40	174.00	6.00	2.00	3.35	62.00	28.00	0.08	0.03	3.41	1.78	14.90	24.90	0.02	0.00	0.07	0.24
	SD	0.54	0.17	27.89	3.28	2.30	1.99	36.00	27.57	0.01	0.02	0.81	1.69	7.77	13.35	0.01	0.01	0.03	0.44
D	Mean	30.00	6.79	199.50	9.00	5.00	6.20	84.00	49.00	0.13	0.05	3.89	3.56	21.65	34.84	0.02	0.01	0.07	1.28
	Maximum	32.00	7.25	223.00	10.00	6.00	7.28	120.00	76.00	0.16	0.06	4.88	5.22	31.20	48.60	0.01	0.01	0.12	1.36
	Minimum	28.00	6.32	176.00	8.00	4.00	5.11	49.00	22.00	0.09	0.03	2.90	1.90	12.10	21.08	0.03	0.00	0.01	1.19
	SD	1.14	0.32	18.52	1.09	0.83	0.87	26.74	21.81	0.03	0.01	0.70	1.38	7.47	10.57	0.04	0.00	0.03	0.44
E	Mean	30.00	6.65	233.50	8.00	3.50	4.94	100.00	58.50	0.10	0.07	4.50	3.78	24.55	41.34	0.02	0.04	0.50	0.65
	Maximum	32.00	6.90	258.00	10.00	4.00	5.96	144.00	88.00	0.14	0.09	5.61	5.35	35.20	58.58	0.01	0.07	0.11	1.16
	Minimum	28.00	6.40	209.00	6.00	3.00	3.91	56.00	29.00	0.06	0.05	3.39	2.20	13.90	24.10	0.02	0.00	0.88	0.13
	SD	1.48	0.17	18.88	2.00	0.54	0.93	38.44	28.50	0.03	0.01	0.83	1.20	9.31	15.37	0.05	0.03	0.02	0.42

Table 26. Water Quality Index Ranking of the Investigated Water Samples

Location	WQI	Ranking
Station A	46.41	Good water quality
Station B	46.163	Good water quality
Station C	43.469	Good water quality
Station D	44.403	Good water quality
Station E	47.12	Good water quality

The textural classification of the soils within the study area is presented in Tables 27 and 28 below. The table presents that the quantity of fine gravel in the soil samples at soil depths of less than 15 cm was observed to be relatively 100 % clay, while for soil samples at 15–40 cm depth was 90 % clay and for soil samples at 40–75 cm depth had 80 % clay content. This is similar to the findings of Chukwu & Musa (2008) and Musa *et al*. (2021). The rating of the soil depths for the irrigation method is presented in Table 29. The drip irrigation method was observed to be best suited for the study area as the water reaches beyond the rooting depths of the plants. In contrast, the soil classification of drainage systems under the various types of irrigation systems is presented in Table 30. The slope rating of the study area is presented in Table 31, which indicates the terraced and non-terraced sections of the study using various irrigation methods.

Table 27: Textural classes rating for surface irrigation system.

Textural classes	Rating for surface irrigation				
	Fine gravel (%)			Coarse gravel (%)	
	<15	15 - 40	40 - 75	15 - 40	40 - 75
CL	100	90	80	80	50
SiL	100	90	80	80	50
SCL	95	85	75	75	45
L	90	80	70	70	45
SiL	90	80	70	70	45
Si	90	80	70	70	45
SiC	85	95	80	80	40
CL	85	95	80	80	40
SC	80	90	75	75	35
SL	75	65	60	60	35
LS	55	50	45	45	25
S	30	25	25	25	25

CL: Clay Loam, SiL: Silty Loam, SCL: Sandy Clay Loam, L: loam, Si: Silty, SiC: Silty Clay, CL: Clay Loam, SC: Sand Clay, SL: Sandy Loam, LS: Loamy Sand, S: Sandy

Table 28: Rating of textural classes for drip irrigation system

Textural classes	Rating for Drip irrigation				
	Fine gravel (%)			Coarse gravel (%)	
	<15	15 - 40	40 - 75	15 - 40	40 - 75
CL	100	90	80	80	50
SiL	100	90	80	80	50
SCL	95	85	75	75	45

L	90	80	70	70	45
SiL	90	80	70	70	45
Si	90	80	70	70	45
SiC	85	95	80	80	40
CL	85	95	80	80	40
SC	95	90	85	80	35
SL	95	85	80	75	35
LS	85	75	55	60	35
S	30	65	50	35	35

Table 29. Soil depth rating for Irrigation

Soil depth (cm)	Ratings for surface irrigation	Rating for Sprinkler irrigation	Rating for Drip irrigation
<20	25	30	35
20 – 50	60	65	70
50 – 80	80	85	90
80 – 100	90	95	100
>100	100	100	100

Table 30. Rating for drainage classes

Drainage classes	Ratings for surface irrigation		Ratings for drip irrigation		Ratings for drip irrigation	
	C, SiC, SiCL, S, SC textures	Other textures	C, SiC, SiCL, S, SC texture s	Other textures	C, SiC, SiCL, S, SC textures	Other textures
Well drained	100	100	100	100	100	100
Moderately drained	80	90	100	100	90	95
Imperfectly drained	70	80	80	90	75	85
Poorly drained	60	65	70	80	65	70
Very poorly drained	40	65	50	65	45	65
Drainage status not known	70	80	70	80	70	80

C: Clay, SiC: Silty Clay, SiCL: Silty Clay Loam, S: Sand, SC: Sandy Clay.

Table 31. Slope rating for irrigation

Slope rating (%)	Ratings for surface irrigation		Rating for drip irrigation		Rating for Sprinkler irrigation	
	Non-terraced	Terraced	Non-terraced	Terraced	Non-terraced	Terraced
0 – 1	100	100	100	100	100	100
1 - 3	95	95	100	100	100	100
3 – 5	90	95	95	100	100	100
5 – 8	80	90	85	95	90	100
8 – 16	70	80	75	85	80	90
16 – 30	50	65	55	70	60	75
>30	30	45	35	50	40	55

The land capability index (CI) and Suitability Classes (SC) were developed for each location at different depths for the various irrigation methods considered in Tables 32 to 34. Table 35 presents the most suitable soil location for surface, sprinkler and drip irrigation systems by notation to CI for the different irrigation systems.

Table 32. CI values and SC for surface irrigation at different depths

Location	15 (cm)	Suitability Classes	40 (cm)	Suitability Classes	75 (cm)	Suitability Classes
1	14.43	N2	30.01	N1	36.93	N1
2	14.43	N2	30.01	N1	36.94	N1
3	17.31	N2	36.94	N1	43.09	N1
4	17.31	N2	36.93	N1	43.10	N1
5	14.43	N2	30.01	N1	36.94	N1

Table 33. CI and SC values for sprinkler irrigation at different depths

Location	15 (cm)	Suitability Classes	40 (cm)	Suitability Classes	75 (cm)	Suitability Classes
1	23.08	N2	41.68	N1	50.87	S3
2	23.09	N2	41.68	N1	50.87	S3
3	23.09	N2	44.5	N1	50.87	S3
4	23.09	N2	44.5	N1	50.87	S3
5	23.09	N2	41.68	N1	50.87	S3

Table 34. CI and SC values for drip irrigation at different depths

Location	15 (cm)	Suitability Classes	40 (cm)	Suitability Classes	75 (cm)	Suitability Classes
1	26.6	N2	47.68	S3	57.6	S3
2	26.6	N2	47.6	S3	57.6	S3
3	25.2	N2	44.8	N1	50.4	S3
4	25.2	N2	44.8	N1	50.4	S3
5	26.6	N2	47.6	S3	57.6	S3

Table 35. The Most suitable soil locations for surface, sprinkler and drip irrigation systems bynotation to CI for different irrigation systems

Location	Soil depth	The Maximum capability index for irrigation (CI)	Suitability classes	The most suitable irrigation systems	Limiting factors
A	0-15cm	26.6	N2	Drip	$CaCO_3$ and drainage
	15-40cm	47.68	S3	Drip	$CaCO_3$ and drainage
	40-75cm	57.6	S3	Drip	$CaCO_3$ and drainage
B	0-15cm	26.6	N2	Drip	$CaCO_3$ and drainage
	15-40cm	47.6	S3	Drip	$CaCO_3$ and drainage
	40-75cm	57.6	S3	Drip	$CaCO_3$ and drainage
C	0-15cm	25.2	N2	Drip	Soil texture, $CaCO_3$ and drainage
	15-40cm	44.8	N1	Drip	Soil texture, $CaCO_3$ and drainage
	40-75cm	50.4	S3	Drip	Soil texture, $CaCO_3$ and drainage
D	0-15cm	25.2	N2	Drip	Soil texture, $CaCO_3$ and drainage
	15-40cm	44.8	N1	Drip	Soil texture, $CaCO_3$ and drainage
	40-75cm	50.4	S3	Drip	Soil texture, $CaCO_3$ and drainage

	0-15cm	26.6	N2	Drip	$CaCO_3$, salinity and alkalinity
E	15-40cm	47.6	N1	Drip	$CaCO_3$, salinity and alkalinity
	40-75cm	57.6	S3	Drip	$CaCO_3$ and drainage

S1 means highly suitable, S2 is moderately suitable, S3 is marginally suitable, N1 is not suitable, and N2 means permanently not suitable.

Surface irrigation systems have been applied to various crops in the study area, including rice, maize, guinea corn, fruits like melons and watermelons, and vegetables like tomatoes, pepper, leafy vegetables, and cucumbers. However, there are limited sprinkler and drip irrigation instances on large farms. A gradual reduction in clay content in soil samples collected at varying depths was observed, indicating that more water will be required to sustain crop growth. The rate at which irrigation water is applied to various farm sections using the three irrigation methods specified in the study was lower than that of the sprinkler and drip irrigation methods.

The slope of the farmlands was observed not to be even in the study area, which affected the amount of water delivered to some sections of the land, especially in the case of surface irrigation systems. This informed the terracing of some farmland within the study area. The CI for drip irrigation systems within the study area were classified as permanently unsuitable, marginally suitable, or unfit for irrigation practice.

Crop yield and water stress are vital, especially in areas where irrigation is practised. This study established the relationship between water stress and tomato and onion crop yield based on experimental results. The physical and chemical properties of the experimental plots were determined between depths of 0 - 15, 15 - 30, 30 - 45, and 45 - 60 cm. The results justified that the soil at the experimental site is suitable for the growth of tomatoes and onions in northern Nigeria upon suitable application of irrigation water. Tables 36 and 37 present the soil samples' physical and chemical properties within the experimental plots.

Table 36: Physical Properties of Soil within the Experimental Plot.

Depth (cm)	Moisture Content (%)	Bulk Density (g cm^{-3})	Textural Class
0 -15	20.7	1.29	Silt Loam
15 - 30	21.9	1.29	Clay Loam
30 - 45	22.5	1.46	Clay Loam
45 -60	25.2	1.31	Clay

Table 37: Chemical Properties of Soils within the Experimental Plot.

Parameters	Units	Values
pH in water		5.2
pH in 0.01	m $CaCl_2^{-1}$	4.8
Organic Carbon	%	0.92
Available Phosphorus	mg Kg^{-1}	26.8
Total nitrogen (NT)	%	0.0
Na+	mg Kg^{-1}	0.89
K+	mg Kg^{-1}	0.38
Mg2+	mg Kg^{-1}	1.40
Ca2+	mg Kg^{-1}	4.83
CEC	mg Kg^{-1}	8.20

The study found that the irrigation water requirement for the study location was 8.46 cm, with a daily water requirement of 0.07128 ha^{-1} mm day^{-1}, a net water requirement of 0.00825 m^3 sec^{-1}, and a 4-day irrigation interval. Treatment 1 showed an increase in onion plant growth rate, suggesting better irrigation for onion bulbs. The analysis of variance for seasonal evaporation (SEE) showed significant differences in crop yield at 5 % (2.57) and 1 % (4.03) levels, indicating that higher seasonal evaporation leads to higher crop water requirements. Similar conditions were observed for tomato growth rate. The results suggest treatment 1 is better for producing better onion bulbs (Figure 5).

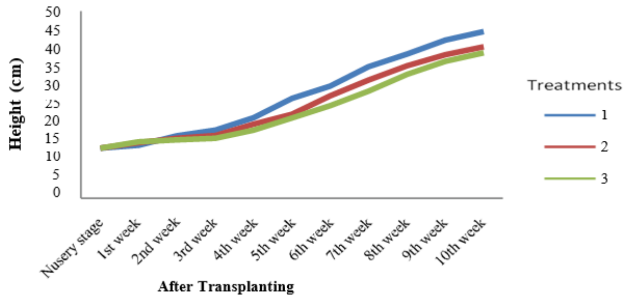

Figure 5. Growth of onion plants concerning irrigation.

The growth stages of onion with ET 243 mm in R_1 treatment 1 had the best growth rate of 85.4 mm compared to other treatments, as observed in Figure 6. This is closely followed by R_1 treatment 2 with a growth of 80 mm at the ET of 232.3 mm, while the least growth was recorded as 71.2 mm in R_4 treatment three, which shows that deficit irrigation has a significant effect on the growth of plants.

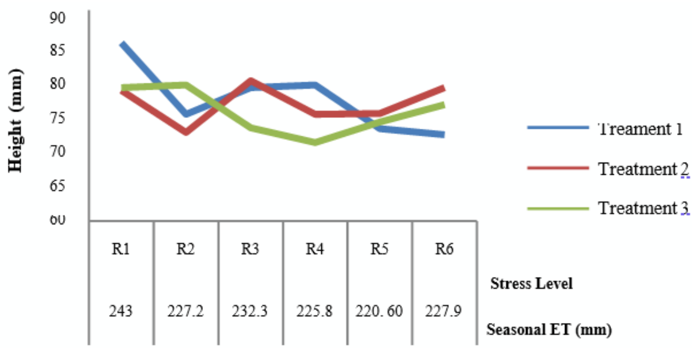

Figure 6. Growth stage and seasonal evapotranspiration (ET) as measured from the experimental plot (mm) for onion.

The highest total yield of onion was recorded at R_3 at 13.4 kg, followed by R_1 at 12.7 kg, and the least is R_5 at 11.5 kg, as observed in Figure 7. The individual yield based on treatments has the best yield at R_3 treatment 1 with 5.6 kg, closely followed by R_6 treatment one, which is the control with 5.5 kg, and the least yield was recorded at R_5 treatment 3 with the value of 2.8 kg.

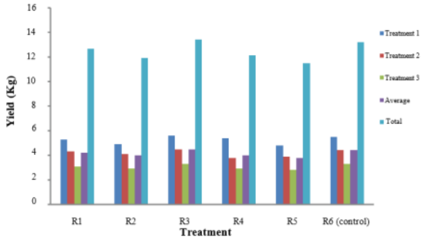

Figure 7. Onion yield (kg) obtained from the experimental plot.

Considering the whole yield based on the seasonal evapotranspiration ET, treatment 1 gave the best yield of 31.5 kg, followed by 25.0 kg in treatment 2 and 18.3 kg in treatment 3 with the ET of 464.5 mm, 458.7 mm, and 453.6 mm respectively. This determined value shows drought stress and scarce water resources are the most significant limiting factors affecting agricultural production. Therefore, there is a need to rank the treatment using LSD of 1.65 value for T_1, T_2, and T_3. Treatment T_1 was more significant than treatment T_2 and is more substantial than Treatment T_3. This result has shown that under critical conditions, irrigation can be conducted at an interval of 10 days since the difference is 5.5 kg.

Musa *et al*. (2019) stated that the growth stages of the tomato from the experimental plot had 87.20 mm, the highest ET value for Y0 of R1, which is the control. Y3 of R1 closely follows this value with a recorded value of 80.00 mm. Almost all the growth stages were within the range of 81.56 - 66.42 mm, except for values from Y_3 for R_3, R_4, and R_5 that were below average (Table 38). The table further shows that the tomato plants for Y_0 had the best growth. This growth may be due to the adequate water supply to the treatment plot, which served as the control plot (Musa *et al*., 2019). The ANOVA statistical analysis shows that F calculated the value of 15.56 for the treatments and 6.93 for the replication were observed to be more than the table values at

5% (3.49 and 3.26) and 1 % (5.96 and 5.41) respectively. The significance level was different for the crop yield, which shows that the higher the seasonal evapotranspiration, the more water the crop required.

Table 38. Growth stages and seasonal evapotranspiration as measured from the experimental plot (mm).

Treatment	R1 (mm)	R2 (mm)	R3 (mm)	R4 (mm)	R5 (mm)	Total (mm)	Average (mm/plot)
Y0	87.20	85.40	79.60	79.00	76.60	407.80	81.56
Y1	79.40	79.40	74.10	73.20	72.30	378.40	75.68
Y2	75.20	73.30	73.30	72.30	71.20	365.30	73.06
Y3	80.00	72.60	62.20	60.00	57.30	332.10	66.42
Total	321.80	310.70	289.20	284.50	277.40	1483.60	283.72

It was observed that the best yield was at $Y_{0,}$ which could be linked to the adequate water supply of the plot, which is the control. This yield from Y_0 was closely followed by Y_1, $Y_{2,}$ and Y_3 respectively. This low yield fell below the total average of yields, which was recorded at 5.44 kg per plot, as presented in Table 39 (Musa *et al*., 2019).

Table 39. Yield obtained from the experimental plot.

Treatment	R_1	R_2	R_3	R_4	R_5	Total (Kg)	Average (kg/plot)
Y0	10.20	10.60	11.30	11.01	10.90	54.01	10.80
Y1	6.20	6.05	6.35	7.28	7.30	33.18	6.64
Y2	3.20	2.90	3.50	3.20	4.10	16.90	3.38
Y3	1.30	1.15	0.40	0.60	1.20	4.65	0.93
Total	20.90	20.70	21.55	22.09	23.50	108.74	21.75

Considering the yield in t ha^{-1}, the results recorded are as follows: Y_0 (4.32×10^{-6}), Y_1 (2.66×10^{-6}), Y_2 (1.35×10^{-6}), and Y_3 (3.72×10^{-7}). From the yield results, it was observed that the control Y_0 had the best yield in t/ha so far while treatment Y_3 has the lowest yield in t ha^{-1}, as recorded in Table 39.

ANOVA result shows that the f calculated value of 458.21 for the treatment was higher than the table value at 5 % (3.49) and 1 % (5.96) level of significant differences in crop yield as it is non-substantial. The F calculated value of 1.58 for the replication was less than the table value at 5 % (3.26) and 1 % (5.41) level of significant differences for crop yield. Therefore, there is a need to rank the means of treatment using LSD at 5 % and 1 % of 27.98 and 42.04, respectively. Y_1, Y_2, and Y_3 were highly significant, where Y1, Y2, and Y3 were stressed for 3 days, 5 days, and 7 days more than 7 days regular intervals, respectively.

The yield of tomato from plot Y_0 had the highest yield of 54.01 kg on the plot where a 7-day irrigation interval was applied; as the irrigation interval increased, the yield decreased, as observed. This yield is closely followed by 33.18 kg and 16.9 kg for Y_1 and Y_2, respectively.

A study in Zukuchi aimed to improve irrigation activities in north-central Nigeria by providing a small-scale structure for farmers during the dry season. A two-canal structure was designed with a discharge capacity of 0.42 m^3s^{-1} to cover an irrigatable area of 5 ha of rice for each canal. However, constant water wastage was discovered due to a lack of control measures. Musa *et al*. (2010) developed software to control water delivery using computer technology, but this technology is limited to areas with limited land availability and owner involvement. Another study examined the use of tube wells for irrigating an average land mass of 5 hectares, using the Blaney-Morinal Nigeria Empirical formula to determine the evapotranspirative water requirement of the crop (Mustapha & Musa, 2008). The study showed that with little water from boreholes, tube wells, and wash bores, it is possible to irrigate large farm areas, provided the soil retains some water for crop growth. Tables 40 and 41 show the textural classification of the soils for the modelled and observed data and the statistical variation between the modelled and observed data.

Table 40: Textural classification of soils for the modelled and observed data

Plot	% Sand	% Silt	% Clay	Textural Classification	Available water		Bulk Density (g cm^{-}	
					Observed	Model	Observed	Model
1	57	11	32	sandy clay	18.55	0.09	1.64	1.44
	56	8	36	sandy clay	18.50	0.09	1.57	1.45
2	61	10	29	sandy clay	16.90	0.09	1.39	1.44
	59	10	31	sandy clay loam	16.44	0.09	1.52	1.44
3	58	20	22	sandy clay	18.12	0.10	1.47	1.49
	51	14	35	sandy clay	15.18	0.10	1.40	1.40
4	48	11	41	sandy clay	16.02	0.10	1.48	1.37
	53	12	35	sandy clay	14.76	0.10	1.46	1.41
5	60	14	26	sandy clay	17.70	0.09	1.50	1.48
	62	13	25	sandy clay loam	20.22	0.09	1.38	1.49
6	56	16	28	sandy clay	17.70	0.10	1.52	1.46
	50	14	36	sandy clay	18.12	0.10	1.46	1.38

Table 41: Statistical variation between the modelled and observed data.

Parameter	% Sand		% Silt		% Clay		Bulk Density (g/cm3)		Moisture content (cm/cm)		Moisture content (cm/cm)	
									Observed	Available	Modelled	Available
Depth of soil	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
N	6	6	6	6	6	6	6	6	6	6	6	6
Mean Value	56.67	55.17	13.67	11.83	29.67	33.00	1.50	1.47	17.50	17.20	0.10	0.10
Standard Deviation	4.63	4.71	3.83	2.40	6.47	4.34	0.08	0.07	0.91	2.11	0.01	0.01

Standard Error Mean value	1. 89	1. 92	1. 56	0. 98	2. 64	1. 77	0. 0 3	0. 0 3	0.37	0.86	0.00	0.00

Musa *et al*. (2020) used the Soil-Plant-Air-Water (SPAW) Model to analyze Soil Water Characteristics and Water Stress Estimates in a specific area. The study found a low silt/clay soil ratio, indicating limited agricultural use and erosion activities. The predominant soil types were sandy clay and sandy clay loam, with sandy clay loam being the most common. The study highlighted the importance of sand percentage in influencing saturated hydraulic conductivity.

The uppermost soil layer showed higher deviations than the lower layer. The available soil moisture content, crucial for plant growth and hydrologic functions, was relatively high in the field compared to the modelled results. The study also found a good relationship between water transmission between different depths and varied soil bulk density values across plots.

Comparing field and model data through t-tests and ANOVA, the study concluded that the predicted data accurately represents the study location's actual status, indicating the SPAW model's reliability in assessing soil parameters.

ENVIRONMENTAL ENGINEERING

Waste management is crucial for environmental health and sustainability, but inadequate practices can have severe consequences. Improper waste disposal, including plastics, electronic waste, and hazardous materials, releases toxins and pollutants into the air, soil, and water, contaminating natural resources, harming aquatic life, and compromising drinking water quality (Otache *et al*., 2014). Open waste burning releases harmful emissions, posing respiratory risks to nearby communities. Waste mismanagement also leads to landfills, which occupy valuable land and emit greenhouse gases, contributing to climate change (Daniel *et al*., 2018). The release of methane from decomposing organic waste in landfills exacerbates global warming. Inadequate waste disposal practices can lead to illegal dumping in natural habitats, threatening wildlife and disrupting ecosystems. Marine environments, in particular, suffer from plastic pollution, endangering marine life and affecting entire food chains (Daniel *et al.*, 2018).

Plate I: Okene dumpsite in Kogi State

Plate II: Angwan Bai dumpsite, Nasarawa State

Plate III: Maikunkele dumpsite, Minna, Niger State

LONGITUDINAL AND TRANSVERSE MOBILITY OF SOME HEAVY METALS ON RECEIVING SOILS OF DUMPSITES IN NIGER STATE, NIGERIA

The study examines heavy metal concentrations in soil samples from dumpsites in Kogi, Nasarawa, and Niger States of Nigeria (Musa *et al.*, 2019). The metals analysed include Chromium (Cr), Copper (Cu), Zinc (Zn), Manganese (Mn), Iron (Fe), and Aluminum (Al). Energy Atomic Absorption Spectroscopy (AAS) was used to determine the concentrations.

The mean concentrations of Copper in Lokoja, Kabba, and Okene were 19.33, 19.67, and 19.5 mg $kg^{-1,}$ respectively. Akwanga, Lafia, and Nassarawa had concentrations of 15.33, 44.00, and 37.33 mg kg^{-1}. Bida, New Bussa, and Minna recorded 33.67, 15.67, and 50.33 mg kg-1 concentrations (Musa *et al.*, 2019).

Soil analysis revealed that Cr, Cu, Zn, Mn, Fe, and Al were present in low concentrations in the study area, with dumpsites showing higher levels compared to reference points 100 meters away. The study found that the concentrations of Copper were within the permissible limit when compared to the EU standard for agricultural soil (200 mg kg^{-1}). However, some dumpsites, such as Borgu, Bida, and Minna, showed higher pollution indices, indicating a need for monitoring and possible reclamation (Musa *et al.*, 2019).

Iron (Fe) concentrations varied across dumpsites, with values below the permissible threshold. Some locations showed high pollution indices, indicating elevated soil Fe content. Manganese (Mn) concentrations were below allowable limits, but some locations, like Kabba, showed higher pollution indices, suggesting moderate ecological risk. Zinc (Zn) was present in all dumpsites within the standard limit, but some locations indicated potential or heavy pollution. Overall, the environmental risk varied across dumpsites, emphasizing the importance of tailored interventions based on regional characteristics.

ORGANIC MATTER AND HEAVY METALS LEACHATE EFFECT ON SOILS OF SELECTED DUMPSITES IN SELECTED NORTH CENTRAL STATES OF NIGERIA

This study aimed to determine the availability of heavy metals (Cr, Fe, Cu, Manganese, Lead, Zinc, and Aluminum) due to municipal solid waste deposition on soils in three Nigerian states: Niger, Kogi, and Nasarawa. Heavy metal concentrations were determined at varying depths to assess pollution extent and the effects of pH and organic matter on heavy metal availability (Musa *et al*., 2017). Heavy metal concentrations were analyzed using an Atomic Absorption Spectrophotometer, pH meter, hydrometer, and titrimetric methods to determine pH, particle size distribution, and organic matter content.

The study found that heavy metal concentration in these catchments was higher than in reference sites but still lower than threshold values. In Niger State, dumpsites in Borgu, Bida, and Minna had the highest concentrations of Mn and Fe across all depths (Musa *et al*., 2019). Cr and Al were more concentrated in Kogi State's Kabba dumpsite, while Zn and Cu had higher concentrations in Nasarawa State's Lafia dumpsite. Variations in heavy metal content among the sampled locations were attributed to waste composition and changes in soil physicochemical properties.

The study also highlighted the role of pH in heavy metal availability, showing that heavy metal distribution increased as soil pH decreased. Cr, Mn, Zn, and Cu concentrations varied across different depths in the soil profiles of all sampled locations (Musa *et al*., 2019). Correlation analysis demonstrated relationships between pH, organic matter, and heavy metal concentrations. In Niger State, Fe and Cu were negatively correlated with organic matter, while Cr was positively correlated with pH.

Table 42: Summary of physicochemical properties of soils surrounding sampling sites in Niger State (NG) dumpsites.

	Depth (cm)	pH	% OM	% silt	% clay	% sand	Textural class
DS	0-5	6.78 ± 0.09	2.20	7.00	10.70	82.30	Loamy sand
	5-15	6.64 ± 0.18	1.50	6.70	11.00	82.30	Loamy sand
	15-30	6.59 ± 0.19	1.20	6.00	11.30	82.70	Loamy sand
RF	0-5	6.81 ± 0.05	0.82	6.70	12.00	81.30	Loamy sand
	5-15	6.72 ± 0.09	0.80	6.70	10.70	83.30	Loamy sand
	15-30	6.63 ± 0.14	0.75	7.00	10.00	83.00	Loamy sand

Table 43: Summary of physicochemical properties of soils surrounding sampling sites in Kogi State (KG) dumpsite.

	Depth (cm)	pH	% OM	% silt	% clay	% sand	Textural class
DS	0-5	6.89 ± 0.05	3.10	10.00	12.00	78.00	Loamy sand
	5-15	6.78 ± 0.11	1.50	9.70	10.70	79.70	Loamy sand
	15-30	6.78 ± 0.00	1.10	11.00	11.30	76.50	Loamy sand
RF	0-5	7.09 ± 0.01	1.02	9.70	10.70	79.70	Loamy sand
	5-15	6.89 ± 0.06	0.95	6.50	12.00	80.50	Loamy sand
	15-30	6.85 ± 0.09	0.91	6.00	13.00	81.00	Loamy sand

Table 44: Summary of physicochemical properties of soils surrounding sampling sites in Nasarawa State (Ns)

	Depth (cm)	pH	% OM	% silt	% clay	% sand	Textural class
DS	0-5	6.62 ± 0.31	2.30	5.00	14.00	81.00	Loamy sand
	5-15	6.58 ± 0.23	2.20	6.30	11.00	82.60	Loamy sand
	15-30	6.33 ± 0.17	1.30	5.00	11.30	82.60	Loamy sand
RF	0-5	6.87 ±0.30	0.89	6.70	12.30	81.00	Loamy sand
	5-15	6.56 ± 0.16	0.83	7.00	12.30	84.00	Loamy sand

15-30	6.40 ± 0.05	0.73	7.60	10.60	81.60	Loamy sand

Table 45: Correlation coefficients (r) between the pH and OM on heavy metals in dumpsite soils tested

Location	Items	pH	OM	Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
	pH	1							
	OM	0.099	1						
	Cr^{2+}	-0.124	-0.169	1					
	Fe^{2+}	-0.356	-0.821**	0.312	1				
NIGER	Mn^{2+}	0.477	-0.643	-0.239	0.3031	1			
	Zn^{2+}	0.501	-0.221	0.527	-0.0091	0.172	1		
	Cu^{2+}	-0.403	-0.738**	0.414	0.849**	0.049	0.274	1	
	Al^{3+}	-0.09	0.126	0.843*	-0.164	-0.374	0.528	0.055	1
	pH	1							
	OM	-0.742*	1						
	Cr^{2+}	0.333	-0.185	1					
	Fe^{2+}	0.832**	-0.643	0.108	1				
KOGI	Mn^{2+}	-0.301	0.159	0.759	-0.413	1			
	Zn^{2+}	0.334	0.008	0.201	0.685	-0.125	1		
	Cu^{2+}	0.827	-0.59	0.770*	0.631	0.203	0.392	1	
	pH	1							
	OM	-0.184	1						
	Cr^{2+}	0.757	-0.548	1					
	Fe^{2+}	-0.143	-0.792*	0.423	1				
NASS	Mn^{2+}	-0.581	-0.077	-0.22	0.482	1			
	Zn^{2+}	-0.563	0.258	-0.305	0.166	0.903	1		

Cu^{2+}	0.296	-0.967*	0.59	0.641	-0.084	-0.36	1	
Al^{3+}	-0.139	0.641	-0.365	-0.371	0.374	0.564	-0.709	1

**Correlation is significant at 0.05 levels (2-tailed) **Correlation is significant at 0.01 levels*.

The physicochemical properties of the soils, including pH, organic matter, and particle size distribution, were presented for each state and analysed across different depths. The soils were generally slightly acidic, with variations in organic matter content across depths. The particle size distribution indicated loamy sand soil in all locations.

DETERMINATION OF ELEMENTAL COMPOSITION OF SOIL SAMPLES FROM SELECTED DUMPSITES IN NASARAWA, KOGI AND NIGER STATES, NIGERIA

The study investigated heavy metal concentrations in dumpsites across various locations in Niger, Kogi, and Nasarawa states. The metals analysed include Chromium (Cr), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), and Aluminium (Al). The metal concentrations were found to follow the order Mn > Fe > Zn > Cu > Cr > Al (Musa *et al*., 2019).

Overall, Mn exhibited the highest mean concentration, particularly in Bida, Borgu, and Minna in Niger State, while Al showed the lowest mean levels across all dumpsites. The mean concentrations of all metals at the dumpsites were higher than those at control sites, indicating anthropogenic environmental contributions (Musa *et al*., 2019).

Considering individual locations, the concentration ranges and mean values varied. For example, in Borgu, Bida, and Minna (Niger State), the concentrations of metals generally followed the order of Cr < Fe < Mn < Zn < Cu < Al. Similar variations were observed in Lokoja, Okene, and Kabba (Kogi State), as well as Lafia, Akwanga, and Nasarawa (Nasarawa State).

Table 46 presents Chromium (Cr) concentrations in the dumpsites were lower than those reported in other Nigerian locations, potentially attributed to deposited waste with high Cr concentrations. Iron (Fe) levels were relatively lower compared to soils near automobile spare parts markets and oil fields. Manganese (Mn) concentrations were above control levels, possibly due to the composition of metal alloys, batteries, glass, and ceramic materials in dumpsites. Table 46 also showed that Zinc (Zn) levels in dumpsites were higher than those at control sites, suggesting anthropogenic contributions, potentially from composted materials and agrochemicals. In most countries, copper (Cu) concentrations in dumpsites exceeded control values but were below maximum allowable limits. Aluminum (Al) concentrations in all sites were consistent with lithogenic origins, indicating no significant anthropogenic input.

The correlation analysis revealed positive and negative relationships among the metals in dumpsites, suggesting complex interactions. The study emphasizes the need to continuously monitor heavy metal concentrations in dumpsites to prevent environmental deterioration and potential health risks. The concentrations generally conform to acceptable limits, but vigilance is crucial, especially considering the increasing industrial growth contributing to heavy metal pollution.

Table 46: Heavy metals content at a dumpsite in different locations (mg kg^{-1}).

Location	Statistical Analysis	Parameters					
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
NIGER STATE							
Borgu	Range	12 to 18	51-79	106-176	19-21	32-36	5-6.8
	Means	18-22	66±14.11	149±37.64	20±1	33.67±2.08	5.7±0.96
Bida	Range	51-79	66-81	50-131	19-28	10 to 24	9.8-16.3
	Means	66±14.11	44±3.0	92.67±40.67	23±4.58	15.67±7.37	12.8±3.28
Minna	Range	19-26	66-81	78-86	12 to 26	31-62	10.8-13.6
	Means	22±3.61	74±7.55	82.33±4.04	20.33±7.37	50.33±16.86	11.87±1.51
KOGI STATE							
Lokoja	Range	17 to 20	27-58	23-39	18 to 23	16 to 22	11.3-20.8

	Means	18.5±3.54	43±15.52	30.33±8.08	20.67±2.52	19.33±3.06	15.7±4.8
Okene	Range	16 to 21	53-63	23-26	33-37	15-24	14.8-18.7
	Means	18.5±3.54	58±7.07	24.5±2.12	35±2.82	19.5±6.36	16.75±2.75
Kabba	Range	19.7-28	20-49	62-76	22-29	12 to 29	10.3-22.3
	Means	23.23±4.29	31±15.72	69±7	25±3.61	19.67±8.62	17.67±6.18
NASARAWA STATE							
Lafia	Range	13-20	20-36	43-66	43-61	13-17	16.3-19.3
	Means	16.33±3.51	27.67±3.51	56±11.79	51.67±9.02	15.33±2.08	17.47±1.61
Akwanga	Range	18-21	29-45	48-62	38-48	33-58	10.2-11.8
	Means	19.67±1.52	35.67±8.33	53.33-7.57	43.33±5.03	44±12.77	13±3.56
Nasarawa	Range	19-27	21-46	20-43	28-31	33-41	10.7-13.9
	Means	22±4.36	32.33±12.67	31±11.53	29.67±1.53	37.33±4.04	12±1.68

CATTLE TREADING EFFECTS ON SOIL PHYSICAL AND HYDRAULIC PROPERTIES IN ABEOKUTA, SOUTHWEST NIGERIA

This research investigates the impact of cattle treading on soil physical and hydraulic properties on a cattle farm in Abeokuta, Nigeria, over two years. The study examined soil properties like bulk density, porosity, compaction characteristics, hydraulic conductivity, sorptivity, steady-state flow, and macroscopic capillary length (Dada *et al*., 2019). The results were analyzed using a One-way Analysis of Variance, and mean differences were found using the Duncan Multiple Range Test at a 0.05 level of significance. The study highlights the adverse effects of cattle treading on soil structure, root development, and water movement.

Plate IV. Cattle paddock in FUNNAB Abeokuta

The study, as carried out by Dada *et al*. (2019), presents a detailed analysis of soil properties and hydraulic characteristics in a paddock with cattle trampling compared to a control site. The particle size analysis reveals that the paddock and control site have predominantly loamy sand texture, with high sand content (77 % - 87 %) and relatively high clay content (11.2 % - 15.2 %), as presented in Table 47. Silt content is low, ranging from 1.8 % - 8.8 %. Porosity within the paddock ranges from 23.8 % - 41.5 %, while the control site exhibits higher porosity levels

(36.6% - 41.5 %). At the 0-10cm depth, bulk density is higher in the paddock and on trampled pathways compared to the control, indicating compaction due to cattle (Dada *et al*., 2019).

Table 47 shows that moisture content decreases with depth increment in all treatments, and the reduction is more significant within the paddock, suggesting that cattle trampling causes a considerable reduction in soil moisture with depth. This is attributed to the reduction in organic matter content with depth.

Soil hydraulic properties, crucial for understanding water flow within the soil, are examined Musa & Gupa, 2019; Dada *et al*., 2019). The sorptivity rate is significantly low within the paddock, indicating a high compaction rate. Hydraulic conductivity is notably low in the paddock compared to trampled pathways and the control, suggesting drainage challenges during heavy rainfall. Steady-state flow is considerably low within the paddock, revealing minimal water flow into the soil. Pore sizes are reduced in the paddock due to cattle pressure, hindering water percolation (Table 48). The characteristic time to gravity shows similar flooding times within the paddock, trampled pathways, and control during light or short-duration rainfall.

Table 47. Soil physical properties with respect to depth (Mean value for two years)

Sample Points	Depth (cm)	Porosity (%)	Bulk Density (gcm^{-3})	Moisture Content (%)	Sand	Silt	Clay	Textural Class
Control	0-10	37.70	1.65	13.20	85.30	2.30	12.40	Loamy Fine Sand
	10-20	41.50	1.55	12.10	83.60	4.20	12.20	Loamy Fie Sand
	20-30	36.60	1.68	9.60	79.90	5.80	14.30	Sandy Loam
Tramped Pathway	0-10	30.90	1.83	8.90	85.00	2.60	12.40	Loamy Sand
	10-20	26.40	1.95	4.60	83.00	4.70	12.10	Loamy Sand
	20-30	38.90	1.62	5.10	81.00	4.70	14.30	Sandy Loam
Within Paddock	0-10	30.20	1.85	10.90	87.30	1.60	11.10	Loamy Fine Sand
	10-20	31.70	1.81	6.50	84.20	2.60	13.20	Loamy Fine Sand
	20-30	23.80	2.02	6.20	83.70	2.00	14.30	Sandy Loam

Table 48. Effects of cattle treading on hydraulic soil properties under different treatments (Mean values for two consecutive years)

Locations	Initial moisture content (%)	Final moisture content (%)	Sorptivity (cm hr$^{-0.5}$)	Hydraulic Conductivity (cm hr^{-1})	Steady State Flow (cm hr^{-1})	Mean pore size (cm)	Macroscopic capillary length (cm)	Characteristic time to gravity (hr)
Control	18.56	46.55	55.75	149.65	157.42	0.41	1.81	0.14
	19.17	36.90	54.96	145.00	156.00	0.67	1.11	0.14
	17.79	48.76	32.32	120.17	122.54	0.27	2.74	0.07
	17.65	42.70	47.97	135.84	141.38	0.32	2.30	0.13
	23.80	52.81	48.29	151.61	15724.00	0.29	2.54	0.10
	16.68	43.02	102.86	198.27	226.40	1.11	0.66	0.23
	34.88	77.63	48.60	131.14	135.00	0.23	3.19	0.14
	42.00	80.22	23.02	65.98	66.95	0.29	2.55	0.35
	24.75	49.10	41.07	127.98	132.83	1.19	0.62	0.10
	40.05	76.48	14.57	66.71	67.78	0.35	2.13	0.05
Mean	**25.50**	**55.40**	**47.00**	**129.20**	**136.40**	**0.51**	**1.97**	**0.15**
Trampled pathways	9.10	16.10	38.21	7.02	37.72	0.14	5.16	0.04
	9.92	26.20	168.93	55.17	155.83	0.66	1.12	0.13
	11.91	26.39	43.83	7.08	43.59	0.44	1.69	0.02
	9.91	24.70	274.50	129.12	195.58	3.18	0.23	0.44
	5.63	20.62	358.05	124.71	292.03	3.68	0.20	0.18
	7.50	28.63	116.33	36.19	120.66	0.29	2.52	0.09
	9.90	26.21	135.28	48.28	127.56	0.48	1.55	0.14
	11.63	27.67	29.15	4.32	29.07	0.20	3.70	0.02
	21.13	38.18	140.77	54.23	128.70	0.78	0.95	0.18
	13.41	30.95	118.49	51.32	107.97	0.77	0.97	0.23
	11.00	**26.60**	**142.00**	**51.70**	**123.90**	**1.06**	**1.81**	**0.15**
Within Paddock	7.52	10.56	1.75	4.06	4.12	0.14	5.42	0.19
	6.83	9.25	4.14	10.51	11.00	0.37	2.00	0.16
	3.45	6.13	1.79	4.46	4.54	0.15	5.05	0.16
	5.22	7.80	1.10	5.63	5.63	0.15	5.00	0.04
	7.88	13.40	1.74	3.84	3.86	0.32	2.24	0.21
	7.13	12.07	0.88	5.75	5.76	0.15	4.93	0.02
	4.60	10.24	0.88	2.46	2.48	0.15	5.10	0.18
	7.48	12.02	1.49	3.63	3.65	0.16	4.74	0.17
	8.20	13.90	0.64	5.28	5.37	0.15	5.07	-0.02
	4.78	7.68	1.37	3.37	3.41	0.11	6.99	0.17
Mean	**6.30**	**10.30**	**2.00**	**4.90**	**5.00**	**0.18**	**4.65**	**0.13**
LSD<0.5	**5.71**	**9.26**	**57.10**	**31.51**	**48.93**	**0.70**	**1.24**	**0.09**

CONCLUSION

Soil conservation is not merely an agricultural technique but a cornerstone of sustainable food security. The need to produce food is growing along with the world's population, placing previously unheard-of strain on land resources. Over the long term, agricultural systems' sustainability is seriously threatened by soil deterioration brought on by pollution, nutrient depletion, and erosion. Given this, soil conservation techniques become essential to protect arable land production and guarantee that future generations can eat the food they require.

Conservation tillage, agroforestry, cover crops, and crop rotation are all examples of effective soil conservation techniques. In addition to preventing soil erosion, they increase soil fertility, retain more water, and support biodiversity. These methods lessen climate change's effects, such as the heightened frequency of floods and droughts, making agricultural systems more resilient. Crops may flourish when the soil is kept healthy, which results in consistent and increased yields.

Additionally, there is an inherent connection between soil conservation and more general environmental sustainability objectives. To mitigate the effects of climate change, healthy soils are essential because they function as carbon sinks, absorbing carbon dioxide from the atmosphere. Water filtering, nitrogen cycling, and the provision of habitat for various species are just a few of the ecological services they provide. We ensure food production and maintain the ecological balance necessary for the earth's health by including soil conservation in agriculture.

The socio-economic aspects of soil conservation must be acknowledged when pursuing sustainable food security. The adoption of conservation methods is made possible by policies and initiatives that support farmers' access to resources, education, and capacity development. For these methods to be successfully used, smallholder farmers who are often the most susceptible to soil degradation—need special assistance. We may develop a more inclusive process of managing soil by promoting community engagement and exchanging indigenous knowledge.

In conclusion, soil conservation techniques are essential to attaining long-term food security. By improving the productivity and health of the soil, they safeguard the cornerstone of our food systems. Putting these ideals into reality is more important than ever as we struggle to feed a rising population and stop environmental damage. Aside from being an economic need, it is morally right to ensure that soil conservation is included in agricultural laws and practices worldwide. Our capacity to preserve and improve the soil that supports us will determine the future of food security. Sustainable soil management may ensure a prosperous future for humans and the environment.

RECOMMENDATIONS

To secure sustainable food production in the face of growing environmental challenges, the following recommendations should be adopted to enhance soil conservation practices:

1. **Promoting Integrated Soil Management:** Governments and agricultural organizations should promote integrated soil management approaches that combine traditional conservation methods with modern technologies. This includes cover crops, crop rotation, agroforestry, and conservation tillage, which help maintain soil structure, prevent erosion, and improve fertility. Integrating organic and inorganic fertilizers can also enhance soil health while minimizing environmental impact.

2. **Capacity Building and Education:** It is essential to fund farmer education and capacity development, especially for smallholder farmers who may not have access to the newest conservation methods. Extension services, seminars, and training initiatives should be increased to spread awareness of sustainable practices and the long-term advantages of soil conservation. A new generation of environmentally aware farmers may also be produced by including instruction on soil management in school curriculum.

3. **Policy Support and Incentives:** Governments should develop and implement policies encouraging soil conservation. This involves offering monetary rewards, such as tax exemptions or subsidies, to sustainable farming farmers. To preserve rich soils for food production, policies should also work to shield agricultural land from urbanization and industrialization. Additionally, international finance and collaboration may greatly aid soil conservation initiatives in underdeveloped nations.

4. **Research and Innovation:** To create and improve soil conservation methods suited to various geographical and climatic circumstances, ongoing study is required. Research funding may

result in breakthroughs in sustainable agriculture, including creating crops resistant to drought, precision farming tools, and techniques to improve soil carbon sequestration.

By implementing these recommendations, we can ensure that soil conservation practices will effectively contribute to sustainable food security, preserving the productivity of our land for future generations.

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Finally, Mr. Vice-Chancellor, distinguished ladies and gentlemen, thank you for being here today to witness my Inaugural Lecture. May the host of Heavens reward you all accordingly.

CITATION OF

ENGINEER PROFESSOR JOHN JIYA MUSA R.COREN, MNSE, MNIAE, MNAE

Engr. Professor John Jiya Musa is a distinguished academic specialising in Soil and Water Engineering, focusing on irrigation and drainage engineering. Born on the 14th day of March 1970, to the family of His Royal Highness, Estu Yankpa Solomon Daniyan Musa (JP), and the late Florence Kulu Musa, in Gakpan, Patigi Local Government of Kwara State. He attended Chapel Nursery and Primary School, Ilorin, Kwara State, and was voted the fastest runner during his early sporting career. He proceeded to Titcombe College, Egbe, in 1980, where he was transferred to the University of Ilorin Secondary School (1982-1987) because of his love for his mother. The state government awarded him the best-graduating science student (West African Examination Council) from the then Edu Local Government Area of Kwara State (1987). He came to the Federal University of Technology in 1989, obtaining a B.Eng. and M.Eng. from the Department of Agricultural and Bioresources Engineering in 1997 and 2004, respectively. He did his mandatory service year in Abia State at Abia Palm Nigeria Limited, where he was retained. He returned to Minna in 1999 to start his master's degree program in 1999. In 2010, he pursued his Ph.D. at the Federal University of Agriculture, Abeokuta, Ogun State, and graduated in 2014.

His illustrious career spans over two decades, from 1994 to 2002, when he worked as a pioneering radio presenter with the Crystal FM (then 91.2 FM) with the radio name Sweet Surrender. In 2005, he joined the services of the Kwara State Fadama II Development Project, sponsored by the African Development Bank and World Bank, where he served as a Deputy Director, Infrastructure Development, and by May 2007, he joined the Federal University of Technology, Minna as a lecturer II.

Over the years, he has held several key administrative positions within the department, school, and university, including level advisor, undergraduate project coordinator, Turnitin officer, and seminar and colloquium committee, where he is currently serving as the chairman. He has participated in numerous committees within and outside the university. Such committees outside the university was the secretary to the Planning and Implementation Committee for the establishment of El-Amin University, Minna; Niger State; Chairman of the PTA of El-Amin Secondary (Day Section), Minna; a one-time church secretary of ECWA Prayer House Nyikangbe, Minna and currently the church secretary of Higher Oil Liquid Fire Ministry, Minna.

Prof. J. J. Musa has extensive experience in teaching, research, supervision, and curriculum development. He has supervised PhD and master's theses focusing on Soil and Water Engineering. He has played a vital role in shaping youth and policy development in agriculture using local technology throughout his career. John has served as an external examiner and research assessor for some universities in Nigeria.

With over 185 publications, John Jiya Musa is currently ranked in the first position at the Federal University of Technology, Minna, Nigeria, among the scholars of Soil and Water Engineering with a University ranking of 37th position. A position he has maintained in the last 4 years. John has presented his research at local, national, and international conferences. He has also acted as an editor for several academic journals and actively participates in capacity-building programs for agriculturists. His collaborations with institutions such as USAID, sponsored NGOs and various agricultural institutions/organisations have further strengthened his agrarian activities in Nigeria.

Prof. Musa's career has been marked by academic excellence, mentorship, and a steadfast commitment to improving Soil and Water Engineering in Nigeria. He is married with two children.

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