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DEVELOPMENT OF A LOW-COST LABORATORY JIG FOR SOIL EROSION STUDIES

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ABSTRACT

A low cost laboratory jig comprising of soil bin and raindrop simulator was designed and constructed. The components assembly of the jig comprises of materials made from wood, PVC, aluminium and iron. Wood constitutes over 60% of the material composition of the jig.The jig was tested under laboratory conditions. It was used for evaluation of soil loss in experiments containing soil loss inducing parameters like rainfall intensity, texture, slope and vegetation cover. Soil loss increased with rainfall intensity .The highest soil loss was recorded for 100 mm/h followed by 50 mm/h and 25 mm/h in that order. There was no significant difference (P>0.05) in soil loss recorded in clay loam and silty clay soils. Sandy loam soil showed greater resistance to soil erosion. Less turbidity was observed for all the samples covered with dense leaves of Anarcardium occidentale, which serves to reduce the direct impact of the simulated rain on the soil particles.The jig was found to be adequate for simulation of conventional standard raindrop. Materials component of the jig were found to be durable. The entire assembly also ensures flexibility in operation. The developed jig was thus found to be appropriate for use in soil erosion studies.

INTRODUCTION

Many factors affect occurrence and degree of soil erosion. Principal among them are water (rainfall erosivity) wind, edaphic (soil related) characteristics and land use pattern [1]. The complex interaction between these factors need to be truly understood and studied in order to have a deep comprehension of soil erosion processes. This would serve to provide baseline information needed to formulate and implement control measures.

Several approaches have been made to study soil erosion [2, 4, 5]. These include stream flow estimation; runoff prediction and forecasting and actual soil loss evaluation using rainfall in agricultural fields. These attempts noble as they were have not proved to be satisfactory by encompassing all the interrelated factors influencing soil erosion as contained in the universal soil loss equation (equation 1).

The soil jig comprising rainfall simulator and soil bin thus come in handy and have been used to study soil erosion processes. It is flexible and allows variation of factors influencing soil erosion under different conditions. Engineers and scientists can use the equipment for training and research on soil erosion studies. Despite the importance of soil jig in research and training on soil erosion studies, the cost of acquiring it through importation is prohibitable in Nigeria. The few available ones in most research centres were acquired more than two decades ago and have become obsolete. Consequently, there is the need to fabricate it with available materials and affordable costs to users. Therefore, the aim of this study is to develop a low cost jig for users on soil erosion studies.

2. MATERIALS AND METHODS

The jig was developed to meet the following requirements:

(i) It should have a capacity to withstand variation of factors influencing soil erosion, as contained in the modified universal soil loss equation[7] .

A = RK L SCP -------------------------- (1)

where A = soil loss; R = rainfall; K = soil erodibility factor; L = slope length; P = erosion control practice; S = slope / gradient ; C = crop management factor.

(ii) it must be easy to operate and assemble.

(iii) materials used for fabrication must be readily available.

(iv) It should be affordable to most users

To meet these criteria, the jig was made of five components. These are the water tank and support; the raindrop simulator; the soil bin and support; the slope adjustment device and the waste collector. White Afara, *Terminalia superba,* tropical hardwood specie was utilized as the major material in fabricating the components. Wood, account for 60% of the whole assembled equipment. The developments of the component parts are as follows.

2.1 ***Water tank and support***: The water tank was made of PVC material. It was cylindrical in shape with a mass of 0.7kg, a capacity of 20 litres (for easy portability) and an outlet control valve, made of the same material. The tank outlet was connected to the rainfall simulator by a 10mm diameter rubber tube. The tank was placed on a wooden frame structure, 1600mm in height. When the tank is completely full with water, it exerts a force of 203 N. The force is uniformly distributed on the wooden structure. The wooden section was selected such that the essential design criteria were met, with enough factor of safety. The design criteria considered are:

(i) Bending criteria[3]:

$$bd^2 \geq \frac{3R_aL}{\sigma_p} \qquad (2)$$

where b and d are selected section dimensions, R_a = end reaction. L = beam length, σ_p = permissible bending stress (σ_p for selected wooden section = 5.6 N/mm^2 (see Table 1).

(ii) Sliding shear criteria[3]:

$$\sigma_{max} = \frac{3F}{2A} \leq \sigma_p \qquad (3)$$

where F = reaction at the support.

Only sliding shear force was considered in the analysis, this is because rolling shear force was negligible, while kinking shear force is too large to exist in the **beam**[3]. For σ_p, the value of 0.64 N/mm^2 was selected as the permissible sliding shear force for the wooden frame (see table 1).

(iii) Deflection criteria[3]:

$$D_{max} = \frac{PL^3}{48EI} < D_P = \frac{3L}{1000} \quad \text{-------- (4)}$$

D_{max} = maximum deflection; P = force on beam; E = Young modulus of elasticity, I = second moment of inertia[3]; D_p= permissible deflection

$$I = \frac{bd^3}{12} \quad \text{---------------------------- (5)}$$

D_p and E for the chosen wood beam were 1.5 mm (chosen from [9]) and 6300 respectively (see Table 1).
The wooden beam section properties were b =22 mm, d = 100 mm.

2.2 *Raindrop Simulator:* It was constructed with aluminium sheet metal of 450 mm length; 425 mm width and 100 mm depth. Based on [7] affirmations that rain droplet size varies between 2.5 and 6.2 mm, a mean droplet size of 4 mm was selected for the design. The aluminium sheet was perforated using drill bit to create 4 mm diameter holes at 6 mm centres. A wooden weir spanning the width of the simulator was created at the inlet section to ensure that flow from the water tank outlet was evenly distributed across the surface area of the simulator plate.

2.3 ***Soil bin and support:*** The soil bin was constructed with wood of 750 mm length, 450 mm width and 75 mm depth. The outlet had a bevelled section to ease discharge of eroded material. The dimensions of the wooden support for the bin are bigger than those of the bin in order to protect it against splashed droplets which may affect its quality and durability. Two hook openings were provided at the front end of the bin support to serve as leverage for the slope adjustment device.

The wooden frame was designed to support the soil bin when full with the heaviest combination of soil materials. The mass of 8.5 kg of empty soil bin combined with full load of sandy soil (the heaviest compared to clay and loam soil) ρ = 1450 kg/m^3 give a load of 443 N which the frame was to support such that the compressive stress [3] (σ_{max}):

$$\sigma_{max} = \frac{F}{4A} < \sigma_{permissible} \quad \text{----------------- 6}$$

$\sigma_{permissible}$ for the wooden section = 4.50N/mm^2 (see Table 1).
The chosen frame section was 50 mm x 50 mm.

2.4 ***Slope adjustment device*** - this devise allows simulation of soil erosion occurrence at varying land topography or soil gradient. Based on observation of soil erosion processes in Nigeria[5], a slope variation in multiples of 4^0 degrees was chosen. This was correlated with the total soil bin length (bevelled outlet inclusive)

$$\tan\phi = \frac{h}{775} \quad \text{-----------------} \ (7)$$

where ϕ is desired slope, h = device height.
A device height of 54mm was computed to be adequate to attain a slope of 4 degrees.

of 775 mm. The device (a wooden material width 450mm) height was thus designed such that

Multiples of this height would give corresponding increase in slope.
Waste collector: This was made of a cylindrical PVC container graduated in litres. It serves to collect the soil laden (runoff) wastewater

2.5 *Components assembly*

The water tank frame support was coupled with the frame of the soil bin by means of detachable bolted (10 mm drilled holes) wooden links. The raindrop simulator was assembled to the water tank frame by means of 10 mm bolted wooden link and a 12 mm diameter connecting rod. The raindrop simulator was located at a height 1600 mm above ground (base) level. The soil bin coupled with the slope adjustment device was fixed with its frame support such that a distance of 1000 mm was created between the raindrop simulator and the soil bin. Thus, the water tank assembly and raindrop simulator functions/operates to conform to the pressurized nozzle simulator, which is capable of producing rain droplet size with a non-zero initial velocity[7]. This simulated droplets had enough kinetic energy to produce erosive effect at contact with the soil material in the bin. Figure 1 shows schematic of the components assembly while table 2 gives the total cost component of the assembly

3. EXPERIMENTAL TESTING

Test running of the laboratory jig was done by utilizing the jig to carry out soil loss determination .These experiments spanned a period of over two months, using the different parameters variation as shown in Tables 3a and 3b. Two loading mass (5 kg and 10 kg) were tested for each treatment parameter combinations (Table 3a and 3b). Each set of treatment combination had experimental test replicated thrice. A total of 486 soil loss evaluation experiments were thus performed using the developed jig. An average of 7 soil erosion studies experiments were performed per day. The jig showed no sign of defects of failure throughout the period of test.

The results showed that soil loss increased with rainfall intensity .The highest soil loss was recorded for 100 mm/h followed by 50 mm/h and 25 mm/h in that order for all soil management conditions, i.e. whether bare, with thin vegetal cover or with dense vegetal cover. This trend was also reported by Nwosu[5] and Hahn et.al.[6]. On the textural variation, there was no significant difference (P>0.05) in soil loss recorded in clay loam and silty clay soils. However, the sandy loam soil showed greater resistance to soil erosion when compared to the remaining two types of soil.

The runoff from the clay soil and silty clay soil were observed to be more turbid than for sandy loam soil. This high turbidity was due to the presence of fine clay material in the two textural classes (clay and silty clay soils).Less turbidity was observed for all the samples covered with dense leaves of *Anarcardium occidentale* which serves to reduce the direct impact of the simulated rain on the soil particles.

4. CONCLUSION

The laboratory soil erosion jig developed here simulated raindrops that gave good approximation of conventional standard raindrop used by Nwosu[5] and Hahn et.al.[6]. When the jig was tested for soil erosion studies, it allows a wide range of factor combinations like texture, slope and vegetal cover to be tested. The performance of the jig during the experimental test proved that the materials used in fabrication were durable and that the jig allowed flexibility in operation. When not in use, the components could be disconnected, cleaned and stored. The jig's total cost of about ₦ 7, 600.00 and the ready availability of its component materials puts it in good stead for acceptance by researchers and experts with interest in soil erosion studies. The jig is therefore presented as being appropriate for use in soil erosion studies in a developing country like Nigeria.

Table 1: Grade stresses for *Terminalia superba* used in jig component parts

	Bending and tension parallel to grain	Compression parallel to grain	Shear parallel to grain	Mean value of modulus of elasticity
Permissible stress value* in N/mm² for 50% grade, m.c < 18%	5.60	4.50	0.64	
Maximum value in N/mm² for chosen section	n-a	0.04	0.069	6,300

* Adapted from [9].

Table 2: Cost of Component parts of the laboratory jig

Components	Cost (Naira)* ₦
Water tank complete with wooden support	1490.70
Raindrop simulator	2576.91
Soil bin and wooden frame support	2299.74
Slope adjustment device (3 nos)	546.84
Waste water collector	390.00
Link rods, bolts and nuts	270.00
Total cost	7,574.19

* 2004 cost estimate.

Table 3: Average soil loss obtained from simulated rainfall intensities at different slopes, soil texture and vegetal cover

(a) Loading mass of 5 kg

Rainfall Intensities (mm/h)	Slope (%)								
	4	8	12	4	8	12	4	8	12
	Bare Soil (No Cover)			Thin Vegetal Cover using <u>Glircida sepium</u>			Dense Vegetal Cover using <u>Anarcardium occidentale</u>		
	Clay loam soil			Clay loam soil			Clay loam soil		
25 mm/h	0.23a	0.31a	0.34a	0.17a	0.22a	0.26a	0.09a	0.12a	0.14a
50 mm/h	0.34a	0.40a	0.45b	0.25b	0.32b	0.37b	0.11b	0.13b	0.15b
100 mm/h	0.44a	0.46b	0.51b	0.31b	0.43c	0.46b	0.14b	0.17b	0.20b
	Sandy loam soil			Sandy loam soil			Sandy loam soil		
25 mm/h	0.08a	0.13a	0.14a	0.05a	0.07a	0.09a	0.04a	0.05a	0.07a
50 mm/h	0.14a	0.18a	0.48b	0.09b	0.11b	0.12b	0.06b	0.08b	0.09b
100 mm/h	0.21a	0.23b	0.50b	0.12b	0.14c	0.15b	0.07b	0.10b	0.12b
	Silty clay soil			Silty clay soil			Silty clay soil		
25 mm/h	0.26a	0.32a	0.34a	0.22a	0.24a	0.26a	0.13a	0.15a	0.17a
50 mm/h	0.28a	0.37a	0.41b	0.25b	0.30b	0.34b	0.16b	0.19b	0.21b
100 mm/h	0.39a	0.42b	0.45b	0.35b	0.39c	0.42b	0.22b	0.24b	0.29b

Means in each column with the same letter in each of the soil type are not significantly different (P>0.05)

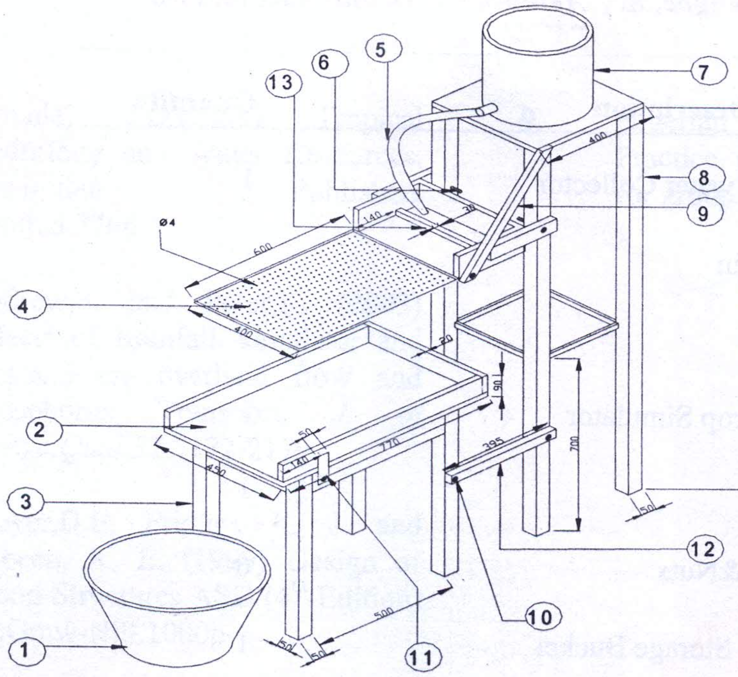

Figure1: Components assembly of the developed soil erosion jig (dimensions in millimetres)

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