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MODIFICATION AND PERFORMANCE EVALUATION OF A SMALL-SCALE RAINFALL SIMULATOR

M. O. Lasisi, F. F. Akinola and O. R. Ogunjimi
Department of Agricultural and Bio-Environmental Engineering, The Federal Polytechnic, Ado- Ekiti, Nigeria

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ABSTRACT
Rainfall simulator is an essential tool to simulate natural rainfall accurately and precisely. A reliable, accurate and portable small scale rainfall simulator is required for runoff, infiltration, sediment generation and erosion studies. And this has been used extensively to gather runoff, infiltration and erosion data in both laboratory and field experiments. This study was conducted to determine rainfall intensity, rainfall drop sizes and erosivity. An existing rainfall simulator was modified to be easily assembled, transported and maintained as well as to create a variety of rainfall regimes. Performance evaluation of the modified rainfall simulator was carried out with 10 trials to determine the intensity of rainfall, drop sizes and erosivity. Correlations were drawn out between the data of the simulated rainfall and that of the natural rainfall data. The results show that rainfall amount, intensity and kinetic energy are the main variables that influence rainfall erosivity index at 99% confidence level. The erosivity index of both simulated rainfall and natural rainfall are 36395.40JM-2mmhr-1 and 34792.51JM-2mmhr-1, respectively. The results of regression analysis of the simulated and natural rainfall show the influence of intensity and amount of rainfall on erosivity index. The linear regression models of simulated and natural rainfall show strong influence to varying degrees of (R2-values) which are 0.949, 0.190, 0.949 and 0.955, respectively. It was concluded that the modified rainfall simulator is suitable to simulate and reproduce natural rainfall characteristics such as rain drop size, intensity, kinetic energy and erosivity. The modified rainfall simulator is a portable type which can be easily assembled, maintained, transported and it can also be used in both laboratory and field experiments for irrigation, infiltration, runoff, sediment and erosion control studies. The estimated cost of modification was ₦44,520.00.

Keywords: Rainfall simulator, Performance evaluation.

1. INTRODUCTION
Rainfall simulators have been used extensively to gather runoff, infiltration, and erosion data in both laboratory and field experiments. Rainfall simulators play an essential role in the studies of soil erosion, sediment generation, infiltration rate and runoff. The system allows soil loss and runoff to be generated under controlled and repeatable conditions. However, the interpretation of simulator measurements is cumbersome by the uncertain relationship between the erosiveness of simulated rainfall and natural rainstorms. A common operating procedure is to select a precipitation intensity, then run the simulator for an essentially arbitrary time (Andraski *et al.*, 1985), or until steady state runoff is achieved (Elliot *et al.*, 1989; West *et al.*, 1991). A rainfall simulator permits the generation of rainfall with a known intensity, period and duration on an erosion field in a maximally controlled manner, making it possible to quantify artificial runoff and soil loss, while at the same time allowing very detailed erosion predictions Martínez- Mena

et al. (2001). Simulators have widely contributed to the understanding of soil erosive processes and though there are some numbers of differences between natural and simulated rainfall, but it is still possible to find good correlations between the values of soil loss measured in an erosion field under simulated rainfall and what occurs in a watershed Hamed *et al* (2002). On the other hand, data generated in the measurements allow calibrating, validating, and verifying erosion predictive models such as Universal Soil Loss Equation-USLE King and Bjorneberg (2011). Rainfall simulators have been used extensively to collect runoff, infiltration, and erosion data in both laboratory and field experiments. The outcome of these experiments are typically used for the intention of understanding phenomenon such as runoff and infiltration mechanisms, water routing, and sediment production and transport at scales ranging from point to hill-slope, with emphasis on how surface characteristics such as slope, aspect, soil properties, fire, vegetation, and micro-topography affect these processes. Foster *et al* (2000). Most recently, research has started to focus on the effects that change in surface properties such as land cover or land use can have on the hydrologic cycle Genxu *et al.* (2012); these studies often assess how runoff and erosion at the field and hill-slope scales change as vegetation recovers from fire, agriculture, or other disturbances. Simulated rainfall has become a useful parameter for researchers studying infiltration and erosion due to the fact that their simulators produce rainfall characteristics that can be replicated at a desirable periods and locations (Bubenzer *et al*.2008). However, as previously stated, it is paramount that the drop size distribution of the simulated rainfall closely mimics natural rainfall characteristics (Beyer, 2001). Raindrop size can vary from mist droplets to drops of 0.24 to 0.28 in. (6 to 7 mm) in diameter, with the median diameter varying depending upon the storm intensity (Harry, 2009). The distribution of drop sizes was found to be correlated to the intensity of the storm event (Laws and Parsons, 1943).

Rainfall simulation has long been used to study the impacts of rainfall on erosion (Birt *et al.* 2007). The need for rainfall simulators arose when researchers acknowledged that simulated rainfall gives more avenues for control over experiments in comparison to waiting for a natural rainfall event to occur to perform experiments. The earliest rainfall simulators used drop-forming mechanisms such as hypodermic needles and string to generate drops (Regmi *et al*.2000). With no pressure in the system, the raindrops had to be released at height as higher to 9 m to make sure that drops reached a speed that is nearer to terminal velocity. Furthermore, these systems were highly susceptible to environmental conditions such as high winds. These constraints limited the use of drop-forming simulators basically to indoor laboratory experiments. During the 1960's, pressurized rainfall simulation systems became more famous as researchers determined to conduct larger scale, outdoor experiments (Romero *et al.* 2011). Pressurized rainfall simulators differ from drop-forming simulators in such a way that they depend on nozzles or sprinkler heads to generate rain-like drops. With a pressurized system, raindrops have the ability to reach terminal velocity quicker, thereby giving room for the design of shorter and more portable simulators. Furthermore, pressurized rainfall simulators give some favourable conditions over environmental conditions and allowed researchers to take their experiments outdoors in similar conditions that practices and products would experience in the field. The ability to take many measurements quickly without having to wait for natural rainfall, to be able to work with constant controlled rain, thereby eliminating the erratic and unpredictable variability of natural rain and it is usually quicker and simpler to set up a rainfall simulator over existing cropping treatments than to establish the treatments on runoff plots. The disadvantages are all related to scale which are; it is cheap and simple to use a small rainfall simulator which rains onto a test plot of only a few square metres, but simulators to cover field plots of say 100 m² are large, expensive and cumbersome. Measurements of runoff and erosion from rainfall simulator tests on small plots cannot be extrapolated to field conditions Cabaula *et al.*, (2000). They are best restricted to comparisons such as, which of three cropping treatments suffers least erosion under the specific conditions of the rainfall simulator test, or the comparison of relative values of erodibility of different soil types and Simulators are likely to be affected by wind, but having to construct windshields derail the advantage of simplicity.

2.MATERIALS AND METHODS

Material Selection

The materials for the modification and performance evaluation of a small scale rainfall simulator include PVC pipes, PVC fittings, galvanized pipe, mild steel, flat bar, plastic trays, and flour pellet were sourced locally.

Inspection and Test Running of the Existing Rainfall Simulator

The existing rainfall simulator was inspected and test run. And adjustments and modification were made on the supporting frame, collector frame, collector, sprinkler nozzles and control valve. Figures 1 and 2 show the existing and modified small scale rainfall simulator, respectively.

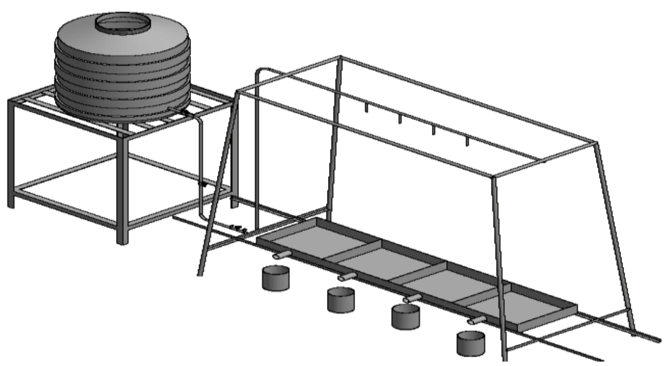

Figure 1: Existing Rainfall Simulator

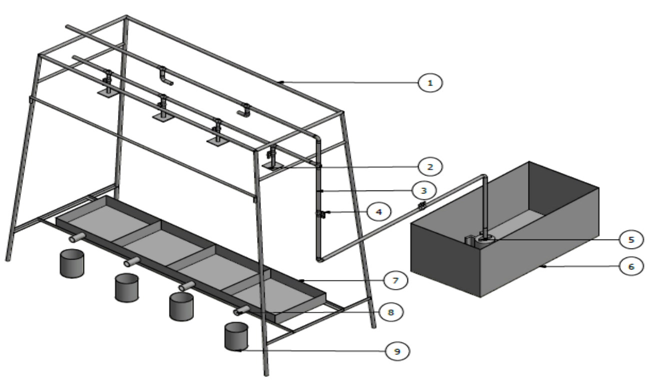

Figure 2: Modified rainfall simulator

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Performance Evaluation Procedure

Evaluation of rainfall intensity

Four catch-cans of a known diameter (8.8mm) were used to collect water drops from the rainfall simulator for duration of 1minute and 30 seconds. The amounts of water in the cans were measured using a measuring cylinder. The values were recorded and the average was determined. This represents the first trial and the whole processes were repeated up to the 10 trial. Finally, the intensity equation was used to determine the drop intensity.

$$I = \frac{rainfall\ amount}{time\ taken}\ (mm/hr)$$

Natural rainfall intensity was determined using the same procedure as above. Four catch cans were placed under a natural rainfall for duration of 1 minute and 30 seconds. The values were recorded up to 10 trials and the intensity was determined using the intensity equation.

Therefore, comparison was done between the intensity of the simulated rain and that of natural rainfall.

Determination of rainfall drop sizes

A tray containing 25mm thick layer of flour was made to pass under the simulated raindrops for duration of 2-4 seconds depending on how quickly the surface layer of the flour is covered with simulated raindrops. The pellets formed as a result of the simulated raindrops hitting the flour surface were allowed to air dry for more than 12hours. The whole contain were screened through a 0.30mm sieve to remove excess flour. Also, any double pellets are removed through this process. The pellets were therefore transferred to evaporating dish and placed in an oven at 43ºc for 6hours. Next, the hardened pellets were sorted according to diameter using the mechanical sieve shaker consisting of sieve numbers, 0.30, 0.60, 1.18, 2.36, 4.75 and 9.6(mm). The pellets were sieved for 10minutes and the total weight and pellet count for each sieved were recorded. The average drop diameter was determined from the flour pellet weight equation.

$$Dr = \sqrt[3]{\left(\frac{6}{\pi}\right) w}$$

Where, Dr= Rainfall diameter, (mm)

W= Average pellet weight, (mg).

The above procedure was done to determine the drop size of the natural rainfall. The tray containing 25mm thick layer of flour was allowed to pass under the drops of natural rainfall for duration of 2-4seconds. The pellets formed were allowed to air dry for about 12hours and later oven dried at 43ºc for 6hours. Next, the hardened pellets were sorted according to diameter using the mechanical sieve shaker consisting of sieve numbers, 0.30, 0.60, 1.18, 2.36, 4.75 and 9.60(mm). The pellets were sieved for 10minutes and the total weight and pellet count for each sieved were recorded. The average drop diameter was determined from the flour pellet weight equation as above.

Evaluation of rainfall erosivity

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Having determined the intensity of both natural rainfall and simulated rainfall, the kinetic energy of the intensities were determined as well since rainfall erosivity is the function of both the kinetic energy and the intensity.

Hence the kinetic energy (E) is given as;

$$E = 29.8 - \frac{127.5}{I}$$

Therefore the erosivity is obtained with (s) = EI_{30}

Where; E = total kinetic energy (Jm^{-2}).

I_{30} = maximum 30 minutes intensity (mm/hr).

3. RESULTS AND DISCUSSION

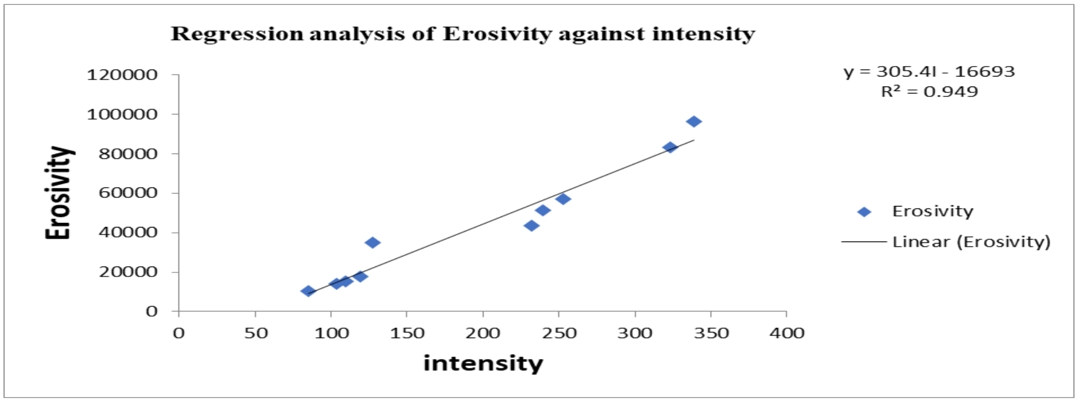

Figure 3: Regression analysis of Erosivity against intensity for simulated rainfall

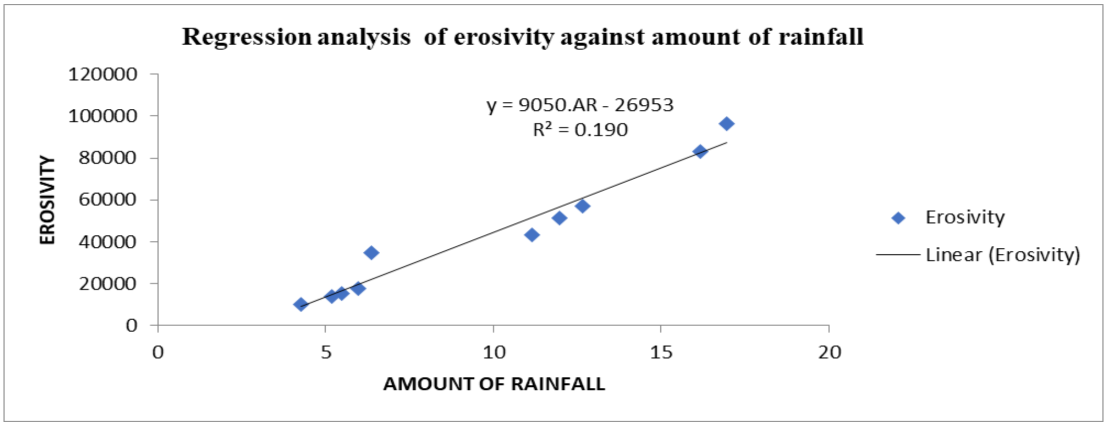

Figure 4: Regression analysis of erosivity against amount of rainfall for simulated rainfall.

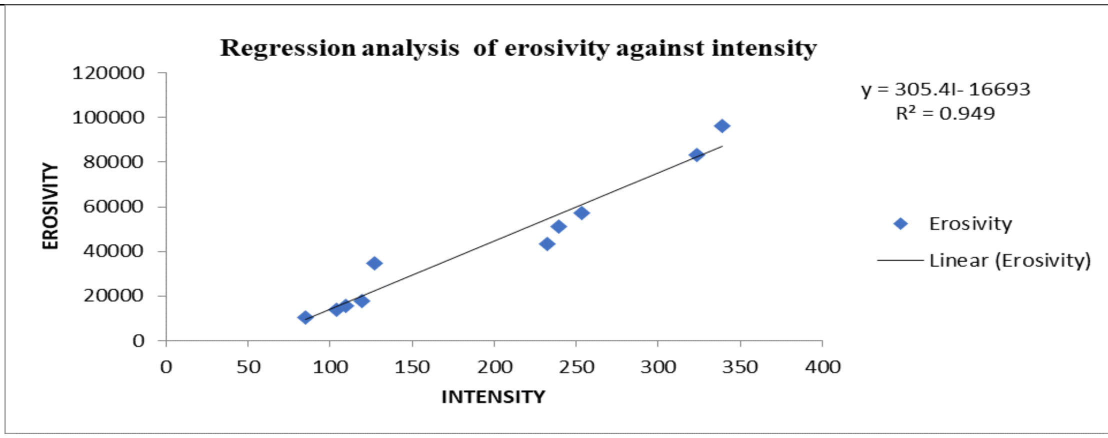

Figure 5: Regression analysis of erosivity against intensity for natural rainfall.

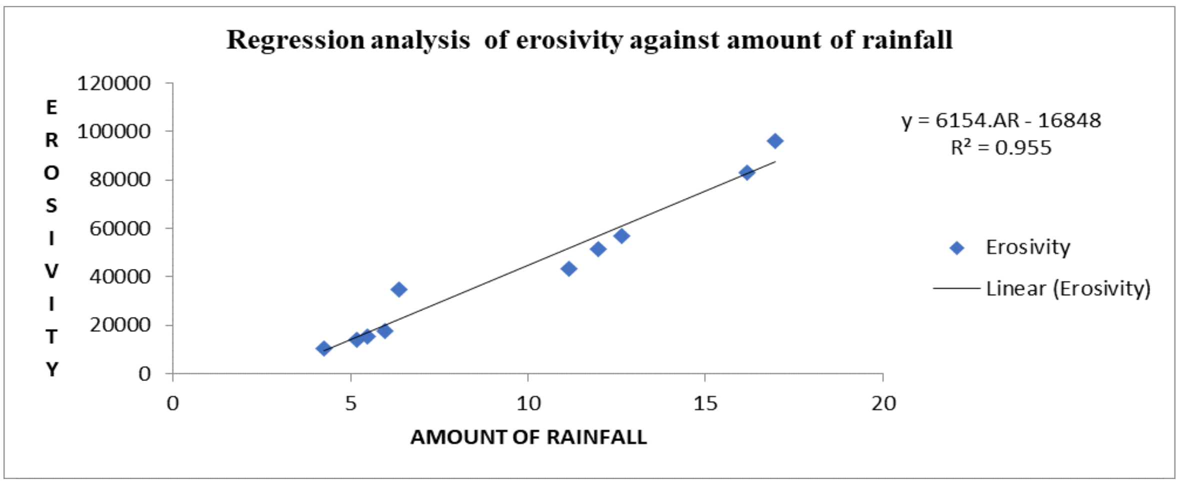

Figure 6: Regression analysis of erosivity against amount of rainfall for natural rainfall.

4.DISCUSSION

The intensity of rainfall was prepared on the basis of 30 minutes durations as described by Wischmeier, (1965) to have more erosive effect. It was observed that the intensities of the simulated rainfall fluctuate as the duration increased. Hence, the maximum 30 minutes rainfall intensity is 14.52mm/hr and the maximum 30 minutes rainfall intensity for natural rainfall is 12.72 mm/hr. Figures 3 and 4 show the Pearson correlation matrix for variables which influence erosivity index of simulated rainfall and natural rainfall respectively. The figures show that amount of rainfall and intensity have high positive correlation also intensity and total kinetic energy have high positive correlations of 99% confident level, which are Variables that influences the rainfall erosivity index. Figure 5 shows the ANOVA dependent variable analysis of simulated rainfall parameter which is highly significant difference at a 95% confidence interval since the p-value (0.000) is less than α – value (0.05). It shows the comparison between parameter where an increase or decrease in amount of rainfall, intensity or total kinetic energy will directly influence the erosivity. Figure 5 shows the ANOVA dependent variable analysis of natural rainfall parameter which is highly significant difference at a 95% confidence interval since the p-value (0.000) is less than α – value (0.05). Figure 6 shows the multiple comparison of dependent variable for natural rainfall where the mean difference is significant at 0.05 confidence level. It show the comparison between parameter where an increase or decrease in amount of rainfall, intensity or total kinetic energy will directly influence the erosivity. Figures 3 and 4 reveal the results of regression analysis of the simulated rainfall showing the influence of intensity and amount of rainfall on erosivity index. The linear regression model shows strong influence to varying degrees of (R^2 - values) which are 0.949 and 0.190. Figures 5 and 6 reveal the results of regression analysis of the natural rainfall showing the influence of intensity and amount of rainfall on erosivity index. The linear regression model shows strong influence to varying degrees of (R^2 - values) which are 0.949 and 0.955. Finally, the erosivity index obtained for both simulated rainfall and natural rainfall are observed to be 36540.60$JM^{-2}mmhr^{-1}$ and 35810.11$JM^{-2}mmhr^{-1}$. These values were obtained from the maximum 30 minutes rainfall intensity as calculated above. There is little difference between the erosivity index of the simulated and that of the natural rainfall. This may be due to some factors such as wind effect and fluctuation in natural rainfall intensity which are beyond man's control.

5.CONCLUSION

This study determined the rainfall intensity, simulate the rainfall drop sizes and evaluate the rainfall erosivity. The modified rainfall simulator is a portable type which can be easily assembled, maintained and transported. The modified rainfall simulator collector can be easily adjusted and tipped at various angles like 60º, 90º, and 120º. The modified rainfall simulator certified the basic requirement to simulate and reproduce natural rainfall characteristics such as raindrop size, intensity, kinetic energy, and erosivity. The modified rainfall simulator can be used in the study of irrigation, infiltration rate and erosion control which are the point of interest in the interplay between vegetation conditions and overland flow generation. This is due to the fact that the basic parameters (rainfall drop size and intensity) of the modified simulated rainfall are similar to the drop size and intensity of the natural rainfall. That is, the drop-sizes are not greater than 7mm diameter. The modified rainfall simulator is a portable type which can be easily dismantled and transported. It can be used in the laboratory as well as on the field for but laboratory and field experiment respectively since the rainfall simulator is similar to some characters of the natural rainfall as showed in the result.

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Vol. 07, No. 03; 2022

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