Research article

Development of Portable Artificial Rainfall Simulator for Evaluating Sustainable Farming in Kenya

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Abstract Artificial rainfall simulation is an important aspect to investigate soil erosion process and surface runoff through application of rainfall simulator. On the other hand portable artificial rainfall simulator can be utilized in remote areas to solve some of the challenges that may be posed by heavy and expensive factory-made rainfall simulators at the same time maintaining the effectiveness and efficiency of the equipment. Drop size, kinetic energy, surface runoff and sediment yield were obtained from experiments conducted using artificial portable rainfall simulator developed in the lab of land and water use engineering for testing on actual fields with different vegetation cover in Kenya. Average kinetic energy and drop size calculated from 24 outlet needles of the rainfall simulator was found to be approximately 1.6 x 10^{-5} J and 3.42 mm respectively. Using calibrated cylinder, intensity was measured randomly along the simulator needle outlets and average intensity calculated as 40 mm hr^{-1}. Water pressure was generated through elevated Marriote bottle. Experiments were conducted in research site in Mombasa Kenya. Drop size and kinetic energy for actual rainfall in Kenya were also determined. Evaluation of soil erosion using portable artificial rainfall simulator is therefore important in establishment of proper and effective soil erosion control strategy for achieving sustainable farming in Kenya.

Keywords rainfall simulator, soil erosion, sustainable farming, portable, Mombasa Kenya

INTRODUCTION

Kenya is located in Eastern part of Africa and It lies between latitudes 5°N and 5°S, and longitudes 34° and 42°E and its total area is 582,650 km^2. It borders five countries (Tanzania, Uganda, Sudan, Ethiopia and Somali) and Indian Ocean on south eastern part. Agriculture in Kenya faces various challenges like water shortage, soil erosion, inadequate technical farming knowledge etc.

Research on soil erosion through application of portable rainfall simulator is among the basic steps necessary in improving sustainable agriculture. Although water is considered as the most critical resource for sustainable agricultural development worldwide (Konstantinos et al., 2015), soil erosion control is also one of the factors considered in enhancing sustainable agriculture. Rainfall aggressiveness has always been a prominent environmental threat in the course of human history, especially affecting the agricultural sector (Nazzareno et al., 2010). Rainfall intensity, drop size, drop fall velocity and kinetic energy are considered in determination of rainfall effect on the soil whereas together with other factors like vegetation cover, land slope, soil erodibility and support practice can be applied to estimate amount of soil loss.

Rainfall simulators have been developed and used extensively for runoff, infiltration and erosion data collection for several years (Roberto et al., 2013). Approximately, for the last 75 years rainfall simulators have been developed and used throughout to conduct research on infiltration, surface water runoff and soil erosion (Humphry et al., 2002). Weight, efficiency, cost and portability are among the major factors considered in development of rainfall simulators. They have produced raindrops either through nozzles or tubing tips like hollow needles. In this research, more emphasis is put on simulators that utilize hollow needles and require lower pressure as compared to those that use nozzles. Development of portable rainfall simulator can be achieved through utilization of readily available materials and a Marriott bottle for evenly distributed water pressure generation.

Many of the existing rainfall simulators are laboratory tools suited for working with disturbed soil samples in shallow trays (Abudi, 2011). Data from the actual fields can yield better analytical results as compared to prepared laboratory plots and provides more actual conditions for further research. Simple design of portable rainfall simulator facilitates extensive research to be done in many fields. In this study more emphasis is put on how to develop portable artificial rainfall simulator and evaluate soil erosion through application of portable artificial rainfall in different fields and appropriate soil erosion control measures to improve environmental factors and also promote economic factors leading to increased farm output.

OBJECTIVE

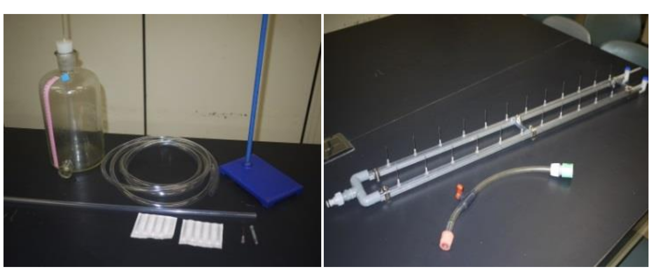
To develop portable artificial rainfall simulator with Marriott bottle and to evaluate soil erosion on agriculture field through observing soil loss in different fields condition under a portable artificial rainfall simulator for sustainable farming practices in Kenya.

METHODOLOGY

Rainfall simulators are commonly used instruments to study sheet erosion, since they can be set to predefined values such as rainfall duration and quantity (Schindler et al., 2012). Development of affordable portable artificial rainfall simulator can therefore be utilized in solving some of the challenges that may be posed by heavy and expensive factory made rainfall simulators at the same time maintaining the effectiveness and efficiency of the equipment.

Materials: Locally available materials were used to develop portable artificial rainfall simulator which includes; 2 pieces of PVC pipes 1 meter long each and 8 mm internal diameter, outlet needles 0.83 mm internal diameter, connecting plastic pipes with control valves, Marriott bottle and metallic stand.

Twelve holes were drilled 8 cm apart on each pipe and outlet needles 0.83 mm internal diameter fixed tightly to allow evenly distributed water drops. Marriott bottle was attached for constant pressure head as shown in Fig. 1.



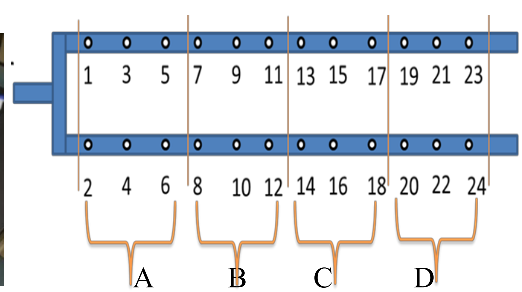


Fig. 1 Materials for artificial potable rainfall simulator **Fig. 2 Needles numbering and grouping**

Using simple metallic stands, developed rainfall simulator was suspended horizontally and firmly at a height of 73 cm from the base and Marriott bottle connected approximately 83 cm from the base to generate equal and evenly distributed pressure and maintain a constant head of water. The experiments were conducted in laboratory to determine intensity, drop size, drop velocity and kinetic energy of the raindrop simulated. Filter paper method was used to determine drop size, whereas camera method was used to determine drop velocity. Kinetic energy is calculated by mathematical relationship of drop mass and velocity. Drops from all 24 needles were collected and considered individually. Also, the intensity of the raindrops from simulator developed were also measured since it is crucial in the relationship between rainfall intensity and kinetic energy and its variations in time and space is important for erosion prediction (Van Dijk, 2002).

Raindrop size measurement: Using a filter paper, drops were collected individually and approximate diameter of each circle formed by the rain drop measured and the average diameter calculated using equation 1. To determine mass of the rain drop, its volume was calculated and multiplied with water density.

$$d = 0.141d' + 0.888 \text{ (m)} \quad (1)$$

$$Vol = \pi/6d^3 \text{ (m}^3\text{)} \quad (2)$$

$$M = Vol * D = Vol * 1000 \ (kg) \quad (3)$$

Where d is assumed diameter of spherical drop (m), d' Diameter of the drop on the filter paper (m), M Mass of the drop (kg), and D Density of water (1000 kg/m^3).

Raindrop velocity: Rain drop velocity was calculated using the camera method and applying equation 4. Distance travelled refers to height covered by a falling raindrop represented by image captured by camera at a known camera shutter speed.

$$\text{Velocity} \left(\frac{\text{m}}{\text{s}}\right) = \frac{\text{Distance (m)}}{\text{Time(s)}} \quad (4)$$

Time represents the camera shutter speed which is set as 1/100 seconds of camera shutter and distance in meters represents the height captured by camera shutter covered by the falling drop.

Raindrop kinetic energy: Raindrop kinetic energy was determined from product of mass and raindrop velocity.

$$KE_D = \frac{1}{2} M_D {V_D}^2 \quad (5)$$

Where KE_D is kinetic energy (J), M_D raindrop mass (kg), and V_D Drop velocity (m/s).

Pressure generated by Marriott bottle: For production of desired intensity over a period of time, it is important to supply equal water pressure which can be achieved by maintaining constant water head

$$\text{Pressure} = h \times \varrho \times g \quad \text{(Pa)} \quad (6)$$

Where h is head difference (m), ϱ density of liquid (kg/m^3), and g gravitational force (m/s^2).

Actual rain drop observation in Kenya: Drop size determination by filter paper method and drop velocity determination by camera method were also applied in actual rainfall in Kenya for comparison with simulated drop characteristics. Several other methods which are more complicated and expensive but more precise are applied to determine the size of the raindrop and drop velocity. The simple filter paper and camera methods were applied for easy and quick comparison with simulated raindrop.

Evaluation of soil erosion through application of developed simulator in the field: Runoff plots were designed by isolating an area in the field of 1.1 m long by 0.2 m wide and sheet metal inserted around to a depth of approximately 0.2 m below the ground. After leaving the place wet overnight, surface runoff was collected at an interval of five minutes. Six samples from each of the four different field conditions were collected and each sample was measured and recorded. Soil lose was also determined by oven drying surface runoff collected.

RESULTS AND DISCUSSION

Raindrop Diameter and Kinetic Energy

Size of raindrop is defined by its diameter assuming that the raindrop is spherical. Size and kinetic energy of each of the twenty four needles was calculated and graphically represented as shown in Fig. 3. Average kinetic energy was calculated as 1.6 x10^{-5} J and raindrop size approximately 3.42 mm. Actual raindrops have different sizes but in average according to many researchers, they ranges between 0.5 mm to 5 mm. Simulated raindrop is therefore within this range.

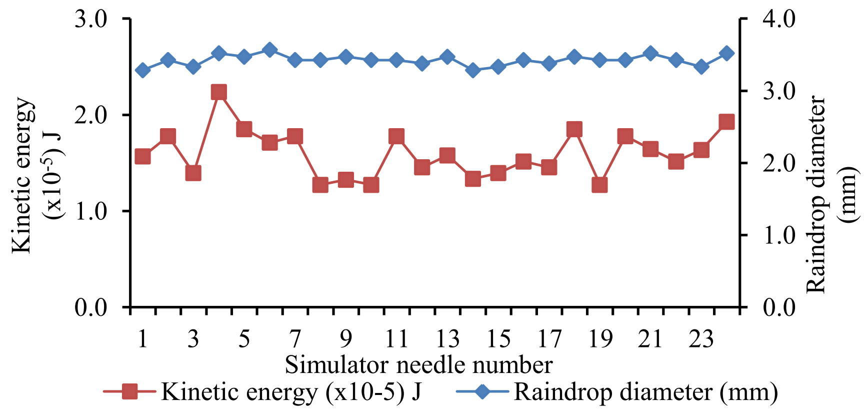


Fig. 3 Kinetic Energy and raindrop diameter

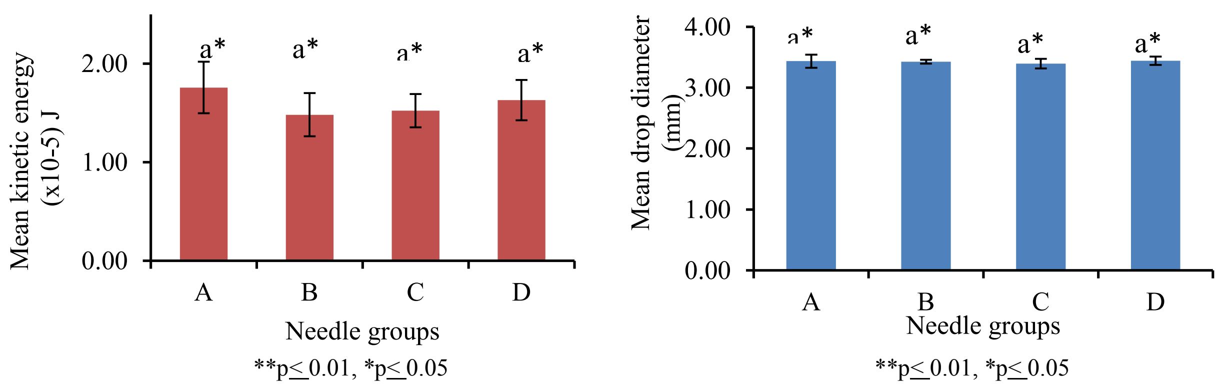


Fig. 4 Mean kinetic energy and mean drop diameter statistical analysis

As shown in Fig. 4, according to needle grouping A, B, C and D, there was no statistical difference among the means for both drop size and kinetic energy. This indicates that pressure calculated as 981 Pa was uniformly distributed among all the needles and the drops impact on the ground is fairly uniform. Also using a measuring container, intensity was measured directly from four sections of the rainfall simulator and average intensity was calculated as 40 mm/hour. Actual rainfall intensity has a wide range depending on the amount of rain per specific time. Raindrop from this developed simulator utilizes gravity and its own weight to fall. Similarly homogeneous pressure generated through Marriott bottle is due to gravity.

Actual Rainfall Drop in Kenya and Simulated Drop Characteristics

Actual raindrops differ with the simulated drops since it's hard to maintain same drop velocity, shape and size throughout the experiment as compared to simulated ones. Therefore, application of camera method and filter paper to determine drop velocity and drop size respectively for actual rainfall was applied purposely to obtain an estimate of these characteristics range and for comparison purposes. After sampling 22 actual raindrops and determining their drop velocity, average velocity was calculated as 1.38 m/s compared to average simulated raindrop velocity of 1.23 m/s. To determine actual rainfall drop size, 58 raindrops were sampled and average drop size calculated as 3.94 mm which is slightly higher than average of simulated raindrop which was calculated as 3.42 mm.

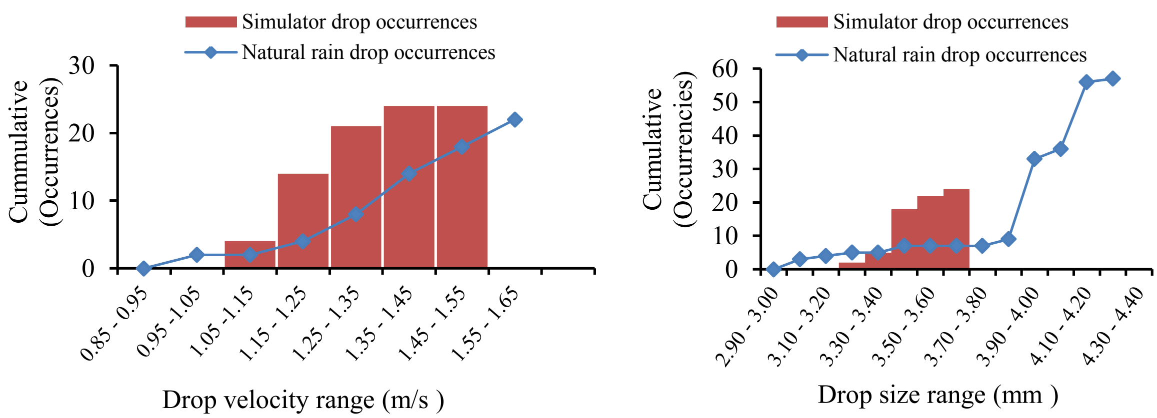


Fig. 5 Natural rain drop and simulator drop relation on drop velocity and drop size

From Fig. 5, drop size, drop velocity and kinetic energy were found to be within the range although actual rain drop size varied greatly. Portable artificial rainfall simulator can therefore be applied in the field to simulate rainfall which is comparable to actual rain for evaluation of soil erosion.

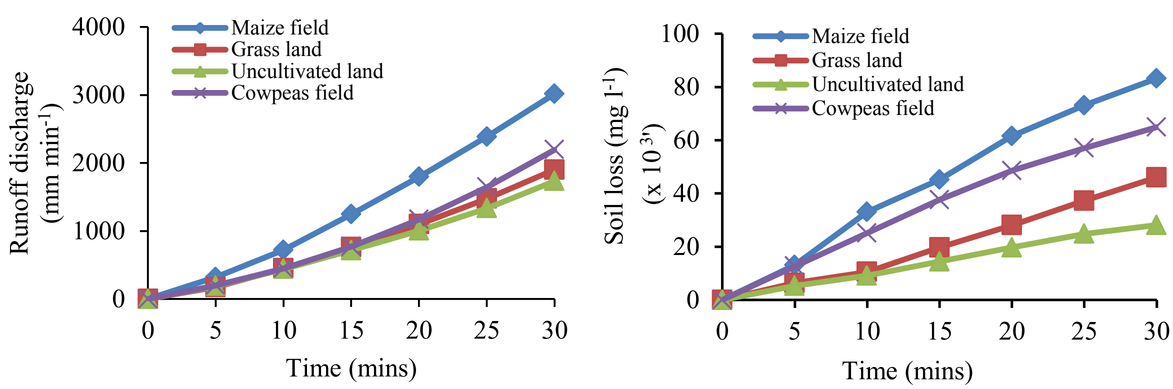


Fig. 6 Runoff discharge and soil loss graphs for different soil field types

Evaluation of Soil Erosion through Application of Developed Simulator in the Field

Surface runoff was collected at an interval of 5 minutes on 1.2 m by 0.2 m plot on undisturbed soil. According to Fig. 6, developed portable rainfall simulator was applied to evaluate soil erosion in four different fields. Quantitative surface runoff and soil loss was calculated. Highest soil loss and highest surface runoff was observed at maize field since the soil was looser due to frequent cultivation as compared to uncultivated field and probably due to less vegetation cover as compared to other fields. This indicates that better soil conservation measures are necessary to reduce soil erosion for sustainable farming practices in Kenya, depending on soil erosion rate, type of soil, water availability, different fields' vegetation cover and amount of rainfall among other related factors.

CONCLUSION

Portability of the rainfall simulator allows the researcher to work in remote areas in Mombasa County and Simple installation can be an added advantage in performing timely, effective and efficient research. Development of affordable and simple but effective artificial rainfall simulator encourages more research on soil erosion to be conducted in different fields which would otherwise been difficult especially in developing countries.

Calibration through experiment indicated that portable artificial rainfall simulator connected to Marriott bottle for pressure generation produces simulated rain drop of approximately 3.42 mm and kinetic energy of approximately 1.6×10^{-5} J for soil erosion impact study. Through statistical analysis the simulated drops had no statistical difference both for the drop size and drop kinetic energy. Moreover, characteristics of the simulated drops were within the range of the actual rain drops in Kenya. This implies that the developed rainfall simulator can be effectively applied in field experiments.

Evaluation of soil erosion using portable artificial rainfall simulator is important since soil erosion is among the leading challenges faced by farmers. Soil with less cover and more cultivated are easily eroded, therefore proper and effective soil erosion control strategy establishment is important for achieving sustainable farming in Kenya. Since terraces are common practice of soil erosion control but less effective, better strategies like thick vegetation cover and trees are recommended to reduce direct contact of raindrops with the soil.

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