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Fabrication and Study of Laboratory Scale Rainfall Simulator for Soil Erosion Assessment

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ABSTRACT

A rainfall simulator is an ideal tool for infiltration, soil erosion and other related research areas for replicating the process and characteristics of natural rainfall. The present paper describes the design of a comprehensive rainfall simulator. In this study a laboratory scale rainfall simulator is developed, which is particularly meant for the assessment of soil erosion at plot scale by considering various soil grain types, soil slope angles and surface exposures under different rainfall conditions. The Rainfall characteristics including the rainfall intensity and its spatial uniformity raindrop size and kinetic energy confirm that natural rainfall conditions are simulated with sufficient accuracy. The comparative measurement was carried out in a laboratory using rainfall simulator fabricated of 4 feet length and 2.5 feet width, where the applied slope angle is 3% with 39 mm/hr rainfall intensity. The runoff and soil loss for different samples were assessed by conducting number of trials. From the results it was found that the soil tilled and keeping it as a bare plot is more prone to runoff compared to soil without tilled and straw mulching has helped to reduce the runoff by 57% as compared to soil without mulching.

KEYWORDS

Rainfall simulator, Intensity, Uniformity, Soil loss, Runoff

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INTRODUCTION

Rainfall simulator has been widely used for studying rainfall and hydrological processes of the soil such as runoff erosion and infiltration. The most important objective of constructing a rainfall simulator is to replicate the process of natural rainfall which is a considerably complex phenomenon and has never been able to be replicated accurately (Aksoy *et al*, 2012). In the last few decades, such rainfall simulator has become a significant tool for analysing the soil erodability with varying rainfall intensity on various soil types and different slope conditions (Grismer, 2012; Mhaske *et al*, 2019). Runoff is an important process related to soil erosion and it depends on natural rainfall and related factors such as variation in intensity, drop size, drop energy, spatial and temporal distribution (Agassi and Bradford, 1999). The main advantage of such instruments is that they can produce a wide range of rainfall intensities as and when required in a controlled environment without having to wait for natural rainfall. However relevant knowledge of the corresponding natural rainfall properties like drop size, rainfall uniformity and kinetic energy are needed to be understood properly. Simulated rainfall has numerous advantages over natural rainfall for various erosion studies. Results from only a few simulated storms at selected conditions often provide the desired information plot maintenance prior to application of such storms is usually much shorter and therefore, less difficult than for studies depending on natural rainfall (Bhardwaj and Singh, 1992). In addition, various measurements and observations which are difficult or impossible during natural rain storms may be readily obtained during simulated storm. Hence, stimulated rainfall is generally more rapid, efficient, controlled and adoptable than natural rainfall.

MATERIALS AND METHODOLOGY

Study Area

The fabricated unit of rainfall simulator is developed at College of agricultural engineering, kandi, Sangareddy which is located at Central Telangana zone. It lies between 78.1270° E longitude and 17.5863° N latitude. The annual rainfall in the study area is 930 mm and soil type is sandy loam. The rainfall simulator consists of mainly three components including container table, simulation unit and controlling unit as shown in Figure 1.

Fabrication of rainfall simulator

An iron framed structure was fabricated with the dimensions of 4 ft length and 2.5 ft width and is supported with water supply system. The horizontal length is provided in such a way to support four soil trays. The vertical frame is made with holes at specified distance to adjust the slope from 0-3%. Full cone spray nozzle of Model- DA 13250 having Spray angle: 45°, Orifice diameter: 1.6mm, Rainfall intensity: up to 65mm/hr manufactured by spraytech used to spray a very uniform distribution. A rectangular storage tank of capacity of 63

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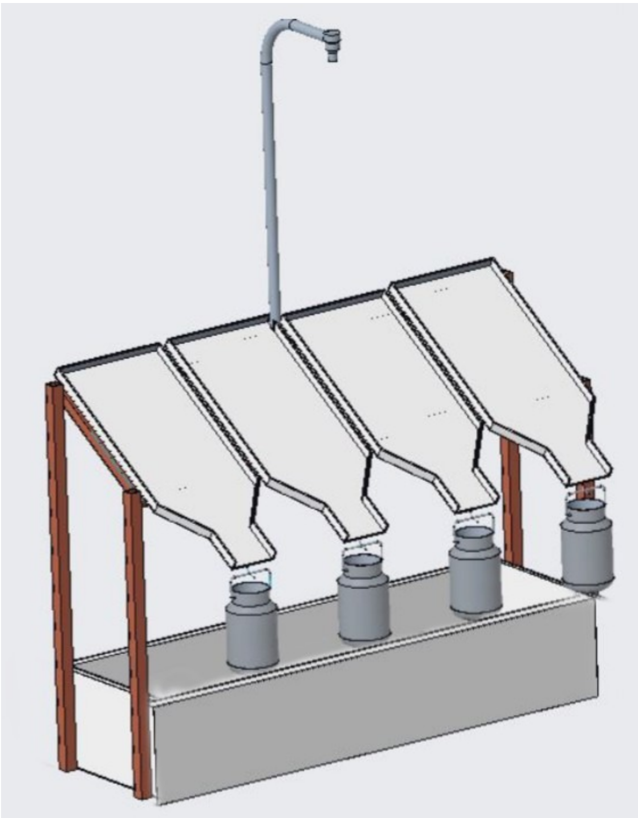

Fig. 1: Schematic diagram of rainfall simulator

litres is used to supply water for production of raindrops. A PVC pipe of size 2.0 cm diameter is connected from pump to the raised head for pressurizing water through nozzle. Measuring jars were kept in the ground below the drip forming mechanism to collect rainfall for calculating uniformity coefficient and intensity of rainfall simulated.

Sample preparation for experimental run

Four different soil samples were collected from four different locations tilled soil, non- tilled, tilled+ straw and non- tilled + straw and analysed the physical properties such as bulk density and initial moisture content (Figure 2). The samples for which analysis to be done were spread uniformly on trays. Trays should be of uniform volume with identical dimensions of length, width and depth with 5mm drain holes in the bottom. Each tray should have uniform soil depth and were compacted to have bulk density similar to field condition.

Fig. 2: Rainfall simulator set up for runoff and sediment-analysis

Performance of rainfall simulator

Rainfall uniformity

Choosing the nozzle spacing will give the best uniformity for simulating rainfall. The uniformity in distribution can be calculated using Christiansen equation (1942).

$$CU = \left(1 - \frac{\sum\left(X - \bar{X}\right)}{\sum X}\right) \times 100$$

x = mean volume of water in the cans (litre)

x = volume of water in each can (litre)

n = number of observation

CU = coefficient of the uniformity and |x - x| = absolute deviation

Kinetic energy of rainfall

Kinetic energy is the most important factor influencing the ability of rainfall to cause erosion. M. The normal equation for kinetic energy is given by Hudson (1993):

KE= 11.9+8.70 log I

Where,

KE= Kinetic energy of raindrop (J/m2/mm)

I= intensity of rainfall (mm/hr)

Sediment and runoff analysis

Position the frame at a height that allows placement of collection below the spouts and also the collection gutters at the front of soil trays mounted on the platform. The tray should be kept in the inclination position with 3% slope and the trays are kept under the overhead nozzle. The excess water generated after infiltration collected in the jars. The runoff collected were analysed for soil loss. The samples were prepared in 1000 ml of glass bottles. The sediment load is calculated for the runoff sample by filter paper. This gives a measure of the concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge.

RESULTS AND DISCUSSION

A laboratory experiment was conducted by fabricating rainfall simulator. The rainfall parameters were analysed by running the test trials. The amount of moisture held by samples were analysed by running the system for 1 hr and collected for oven drying. The results showed that values of soil moisture increased by 16.1%, 9.83%, 22.69% and 31.17% respectively for tilled soil, tilled+ straw mulch, non-tilled, non-tilled+ straw. High increase in soil moisture found in case of non-tilled soil because of dry condition before the storm and more time to absorb moisture whereas low in case of tilled soils. The replications showed that tilled soil attained moisture quickly and more runoff water collected as compared to non-tilled soil from Figure 3 and Figure 4 .

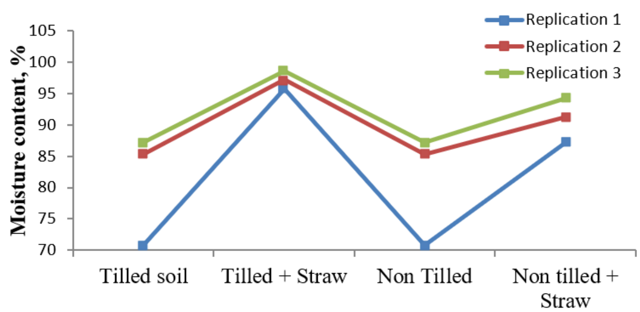

Fig. 3: Variation in AMC of samples before and after the storm

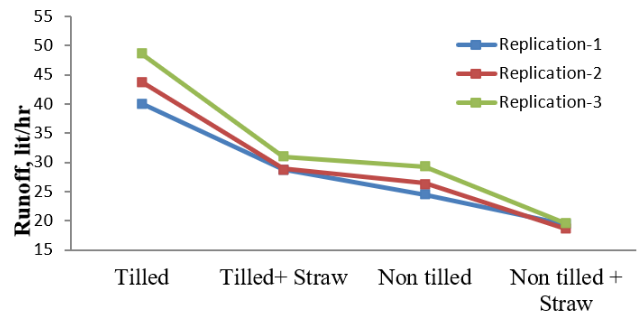

Fig. 4: Volume of runoff generated for different replications

It is also observed that straw mulching has helped to reduce the runoff to 57% as com pared to soil without mulching. However, the soil which is not tilled and covered with straw is also having the less runoff about 41% compared to tilled soil covered with straw mulch. From the results, it can be concluded that the soil tilled and keeping it as a bare plot is more prone to runoff compared to soil without tilled. Soil loss found to be reduced by 43% by covering soil with straw mulch layer in case of both tilled as well as non-tilled soil. Antecedent moisture values of different samples before and after the storm and Observed Runoff and Sediment loss for different samples presented in Table 1 and Table 2 , respectively.

Table 1: Antecedent moisture values of different samples before and after the storm

Replications	Moisture content (%) for different Samples							
	Tilled		Tilled +Straw		Non-tilled		Non-tilled +straw	
	Before storm	After storm	Before storm	After storm	Before storm	After storm	Before storm	After storm
1	70.80	95.74	70.80	87.25	89.83	67.94	89.83	54.360
2	85.30	97.23	85.30	91.32	93.21	69.23	93.21	62.30
3	87.20	98.63	87.20	94.22	95.36	72.56	95.36	68.24

Table 2: Observed Runoff and Sediment loss for different samples

Parameters	Soil type											
	Tilled			Tilled+ straw			Non-tilled			Non-tilled +straw		
	1	2	3	1	2	3	1	2	3	1	2	3
Runoff (lit/hr)	40.1	43.8	48.6	28.7	28.9	31.0	24.5	26.4	29.3	19.4	18.6	19.5
Sedimentation (gm)	106	112.8	130.6	39.8	41.3	46.7	165.5	180.6	197	45.9	45	48.2

The setup mainly consists of a water supply system with a single spray nozzle, and supporting metal frame, soil slope adjusting container table. The unique features of the rainfall simulator is that easy to build, can be handled easily by a single individual and is able to simulate rainfall whose properties are close to natural rainfall Conditions. The uniformity in distributing the rainfall found as 70% for a generated rainfall intensity of 39 mm/hr and Kinetic energy of 27.67 J/m^2.mm. According to Laws (1941), it is that for the simulated rainfall intensity of 25 mm/h attain the kinetic energy of 24.053 J/m^2/mm after a fall of 0.5 m. The bulk density results showed that tilled soil was prone to more compaction than non-tilled soils and consequently the porosity also affected. The value of runoff is more in case of soils tilled and kept uncropped. However, tilled soil covered with straw is in agreement with non- tilled soils.

CONCLUSION

This study primarily presents the comprehensive design of a laboratory based rainfall simulator for conducting soil erosion experiments on laboratory scale. From the analysis, it is found that runoff and soil loss both are showing inverse relation in tilled and non- tilled soils. Further research need to be done for various height & operating pressure of rainfall simulator, which plays a major role in producing uniform rainfall.

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