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Development of rainfall simulator to observe the real field runoff on sweet orange (*Citrus X sinensis*) orchard

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Abstract
Precipitation plays vital role in hydrological cycle. Precipitation can infiltrate into soils, become surface runoff and/or can be intercepted by vegetation. Rainfall interception by vegetation is an important factor in hydrological models, accounting even for major proportions of total precipitation. Reliable quantitative estimation of such losses thus remains a big challenge for hydrologists and therefore required to have some realistic observed results. The interaction between vegetation and rainfall is of considerable significance from physiological, ecological, and hydrological points of view. In any of the hydrological model application the accuracy of prediction largely depends upon the precision with which the precipitation loss functions are quantified. The construction and fabrication of rainfall simulator was completed in the College of Agricultural Engineering & Technology, Godhra. Present study was undertaken to develop a simple, economical and adjustable rainfall simulator of 5 m (16.40 ft) vertical height and 1.5 m (4.92 ft) horizontal length to conceive rainfall, runoff and losses (interception, infiltration, evaporation etc.) with elapsed time. Study revealed that initiation of runoff was few minutes later for all trees due to initial abstractions and equilibrium attained in between 19 to 24 minutes after starting of artificial rainfall. Trees having extensive canopy area and longer in height require more time compare to limited canopy area and shorter in height to attained runoff equilibrium.

Keywords: Portable rainfall simulator, sweet orange, rainfall, runoff, shower, canopy area and height of trees

1. Introduction

Precipitation is the key element in hydrological cycles. Principle components of the hydrological cycle are evaporation, transpiration, evapotranspiration, infiltration, runoff and losses. Runoff from rainfall primarily depends upon rainfall characteristics, land type, land cover and weather type. The effectiveness of plants in improving soil quality and controlling runoff and soil loss depends on variations in plant morphology and architecture (Bochet *et al.* 1998; Gyssels and Poesen 2003; Casermeiro *et al*. 2004) [1, 6, 3].

The rainfall simulators are essential tools for investigating hydrologic processes on arid and semiarid rangeland where rainfall events are sporadic. Simulator experiments can be used to estimate infiltration, inter rill erosion runoff rates and chemical water quality for given storm events. Impacts of range management practices (grazing strategy, brush control, reseeding) on the watershed can also be evaluated using rainfall simulators. Rainfall simulators can be used to collect data in a relatively short period, than long period of the 10 to 20 years. Rainfall simulators also provide maximum control over plot conditions and rainfall characteristics.

Runoff plots have long been used in soil erosion research to evaluate various cropping and management systems on different soils under natural rainfall. 10 to 20 years of measurements have been required to obtain representative sampling of natural rainstorms to fully evaluate treatment effects. Naturalrainfall-runoff plots have also been found useful by researchers but they are costly to establish and maintain over such long periods. In recent years, rainfall simulators have been used extensively to hasten the accumulation of information from runoff-erosion studies. These simulators give controlled application of rainfall closely resembling the drop characteristics and kinetic energy of natural rain. Preselected rainstorm intensities and durations are applied to plots on which new or untested cropping and management practices have been established. Hardly we found any such simulator which are portable, and permits relatively rapid testing of many variables in real field conditions. To more accurately interpret and apply the results of studies using a rainfall simulator, it is necessary to know the relative effects of natural versus simulated rainfall. This knowledge can then be directly related to mosterosion and runoff studies for quantitatively evaluating soil erodibility.

The real field observations and the data is seldom available in this regard owing to enormous reasons like complicities in measuring instrumentations and their feasibilities together with cost factor too.

2. Material and Methods

Considering all above factual scientific issues and demands, present study was undertaken to observe and consequently relate the patterns & effects of simulated rains over variety of sweet orange orchard by developing small artificial rainfall simulator. Even than we need to start from some point with some efforts. Present study was planned to take a first step in this direction and initiate to generate some preliminary sets of observed data on artificial rainfall, runoff and losses in a controlled area encompassing variety of sweet orange orchard.

The construction and fabrication of rainfall simulator was completed in the College of Agricultural Engineering & Technology (CAET), Godhra Work shop and trials were accomplished first inside the college campus, followed by research farm. The experimental site of this study is located at Kakanpur village under tribal dominated Panchmahals district of Gujarat and it encompasses an area of about 20 ha. The climate of study area is semi-arid with limited scattered rainfall but events of unusually higher intensities and shorter durations. Soils are approaching towards a sandy soil category being dry and gritty to the touch. Its general textural composition remained in the ratio of about 40:40:20 for sand: silt: clay, respectively. The objective of this research was to develop a simple and economical device called rainfall simulator to measure the rainfall, runoff and losses of sweet orange orchard in real field condition. Materials and instruments used in this study are as follows.

Table 1: Material used in experiment

Material	Purpose
Shower	For artificial rainfall
Portable stand	To mount a shower
Syphon pipe (0.5”)	To convey the water from pump to PVC pipe
PVC pipe (0.5”)	To convey the water from syphon pipe to shower
Strainer	To prevent the foreign matter
Chiffon	To prevent the minor materials i.e., algae and sediments
Rubber gasket	To prevent leakage of water from shower
Monoblock pump (0.5 hp)	To withdraw water from water tank
Valve	To control the flow of water
Water tank (6000 lit)	To store the water
Electric wire	To connect the motor for electricity
Adjustable locking system	To adjust the height and lock the horizontal pipe
Iron thread	To tie the PVC pipes with iron pipe
Other accessories	Glue, insulating tape, plier nut and bolts, scale, M-seal, data record sheet, etc.
Measuring Device	**Purpose**
Bucket (16 lit)	To measure the runoff at an outlet
Jar (300 ml)	To measure the amount of water below 1 lit
Stopwatch	To note down the time
Measure tap	To measure the height of plants
Pressure gauge (0-7 kg/cm^2)	To observe and maintain the pressure

Table 2: Number of holes in different rows on shower

Rows no	No. of holes	Rows no	No. of holes
1	34	9	17
2	32	10	16
3	32	11	11
4	30	12	10
5	30	13	6
6	25	14	4
7	25	15	1
8	20	Total	293

2.1 Fabrication of showering components

The shower was madefrom locally available material “Tapeli” (aluminium) at the college work shop in which we made 293 holes of 0.5mm diameter with the help of drilling machine. The horizontal spacing between two holes were kept 10cm and vertical were kept 5cm. Number of holes per row drilled on shower is given in Table 2. A shower assembly was fitted with analuminium cover by using a rubber gasket to prevent the leakage of water and entire shower was air & water tightened by driving 35 nuts and bolts on the circumference of “Tapeli” as shown in line sketch diagram assembly (Figure 1). The finally arrived assembly to work as shower utilizes different kind of materials which were chosen from variety of alternate options. For different components of rainfall simulation set up different kind of simplistic and economical materials were opted

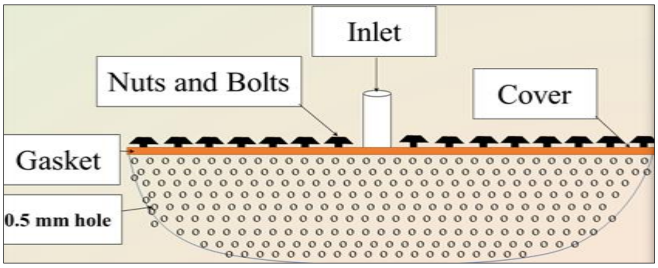

Fig 1: Line sketch of shower

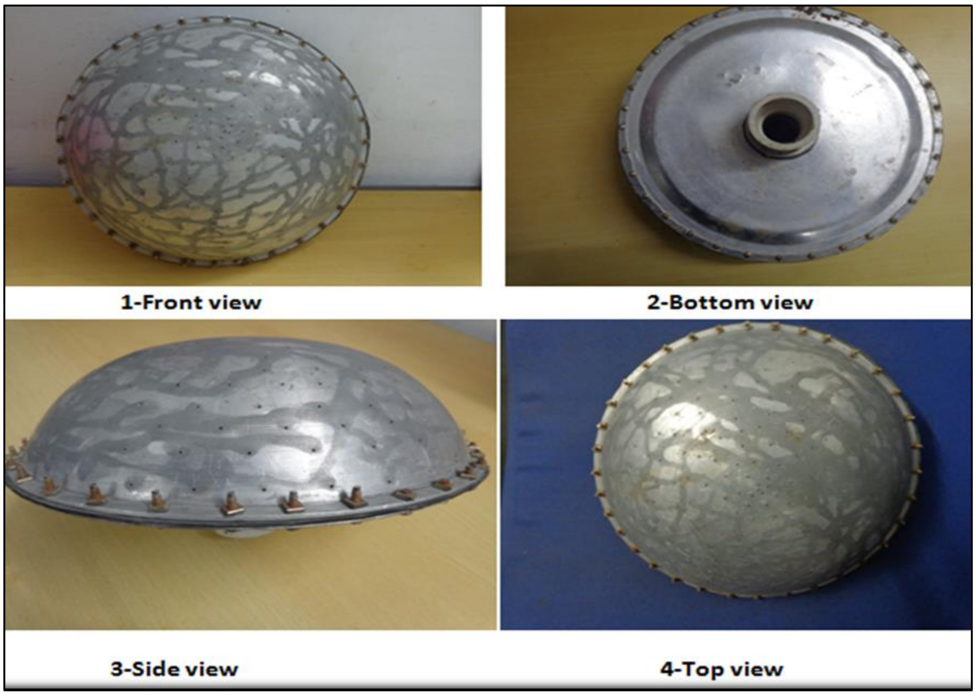

Fig 2: Different views of shower

2.2 Fabrication of portable telescopic rainfall simulator stand

A light weight, telescopic, portable economic stand was conceptualized, framed and constructed to mount upon showering assembly, inlet supply pipes, output setupsand pressure regulating mechanism with total transportability of assembly. The stand was constructed in work shop from low weight cast iron which is hollow. Associated tripod was too made of caste iron pipe having rectangular cross section with modified branches/frame in swastika shape. It was kept with an arrangement with which it is always possible to adjust the positions of input and output pipes at different optional configurations in vertical and horizontal directions. A final view of this arrangement is shown in Figure 3.

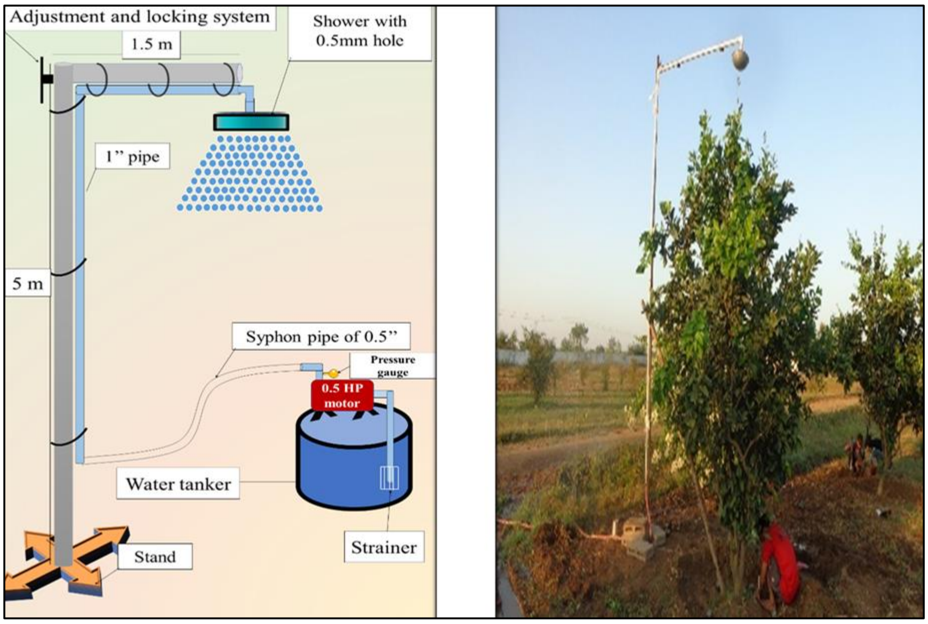

Fig 3: Line sketch and real field view of rainfall simulator

2.3 Preparation for field experiment

A circular peripheral was prepared around the sweet orange plant covering entire canopy and circular pit was dug down at the outlet with approximate 1% slope to put the bucket as shown in Figure 4. A volumetric measurement method was adopted where the volumes and time to fill that volume was precisely recorded. Generated runoff was collected in the bucket of 26.75 cm diameter and 28.5 cm heighthaving storage capacity of 16 litre. Jar of 300 ml was also used to measure the quantity of water less than 1 litre. The initial moisture content before staring of experiment was ranged in between 2 to 4 per cent in soil for all trees. The simplistic low-cost runoff simulation set up comprised one shower of relatively high circumferential area to offer homogeneous rain showers over the fuller extent of projected tree canopies of various orchards at appropriate normal heights of tress. The existing heights and canopy coverage of each of 3 trees under experimentation was accommodated by adjusting the horizontal and vertical sliding bars of rainfall simulating assembly i.e., on stand ends.

Fig 4: Measurement of runoff through volumetric method

2.4 Calibration of rainfall simulator

The assembly used for rainfall simulation was effectively calibrated by measuring the quantum and rates of simulated rainfall. A simple volumetric approach was adopted where repeated calibrations were performed by observing sets of data pertaining to observed volumes and times under varied runs. Average values were taken as input rainfall intensities, based upon which other conversions/forms of this input were observed and recorded. Rainfall intensity values were worked out by using bucket and getting inside all the volume of simulated rains at a location closest to shower, which is termed as calibrated volumes and rates of simulated rains. The real field procedures to do so is shown in Figure 5.

Fig 5: Calibration of input rainfall intensities during simulation

2.5 Recording simulated rains

The showers acted in a manner that artificial rains fallen on top of tree canopy and making it possible that the rain drops travels along surfaces of leaves as well as stems to reach up to ground at varied point of times. Whole runoff generating mechanism was closely observed by team to independently records various time nodes after functioning of rainfall simulation setup. These time nodes consisted time when rain strikes 1st time on trees, water fall in the bucket and time needed to fill up the bucket (16 lit). Also, intermittent volumetric observations were generated at close intervals by using the glassed jar of 300 ml and stop watch. This all together provided a realistic observation on runoff rates, which was ultimately utilized for computing the loss rates, by data integration/differentiations.

2.6 Deriving losses from simulated rains

During a rainfall event, not all rainfall will become direct runoff or contribute to the stream flow at the catchment outlet, rather a part of the simulated rainfall is get lost owing to interception by vegetation and to soil through infiltration. The loss due to evaporation and transpiration are also there, but these were considered negligible here. The quantum of pooled losses (i.e. interception & infiltration as major components and through fall & depression storage as minor components) could be easily derived by subtracting the observed runoff from simulated rainfall.

$$\text{Runoff} = \text{Rainfall} - \text{Losses} \qquad (1)$$

2.7 Measurement of physical dimensions of sweet orange orchard

Height and canopy of the plants were measured with help of ranging rod and measuring tape. Uppermost part of the plant to the ground surface was consider for height. Two ranging rods were kept offset to measure the diameter and these measurements were taken from several sides as shown in Figure 6. Average canopy diameter was taken from several offset diameter of sweet orange tree and then canopy area was calculated. Canopy area of sweet orange tree was calculated by taking an average of several offset diameters to utilize for circular canopy spreads.

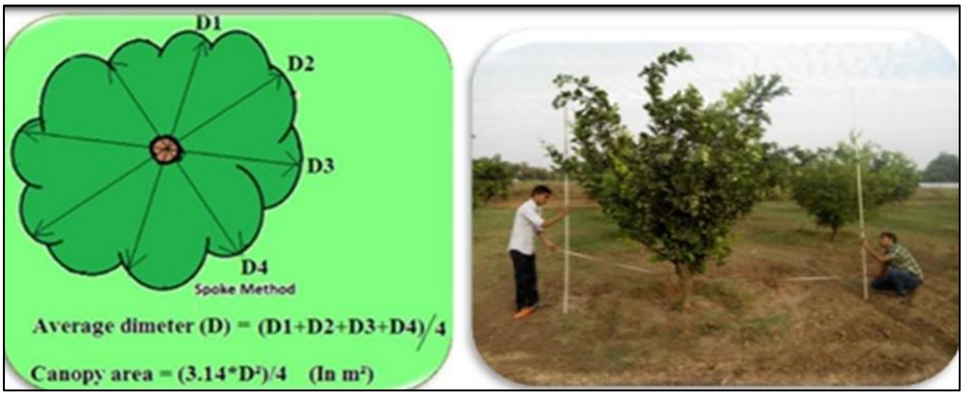

Fig 6: Height and canopy measurement of trees

3. Result and Discussion

Sweet orange orchard was selected such that they are almost regular in shape, canopy area and height and feasible to rainfall simulator height and width. Physical dimensions of the plants such as height and canopy area are illustrated in Figure 7. S1 plant having height and canopy area are 4.3 m and 26.4 m^2, respectively. S2 plant having height and canopy area are 4.0 m and 25.7 m^2, respectively. S3 plant having height and canopy area are 3.9 m and 23.7 m^2, respectively. S1, S2 and S3 trees were choosen such that having height and canopy area are in desceding order so effect of runoff can be clearly recognized.

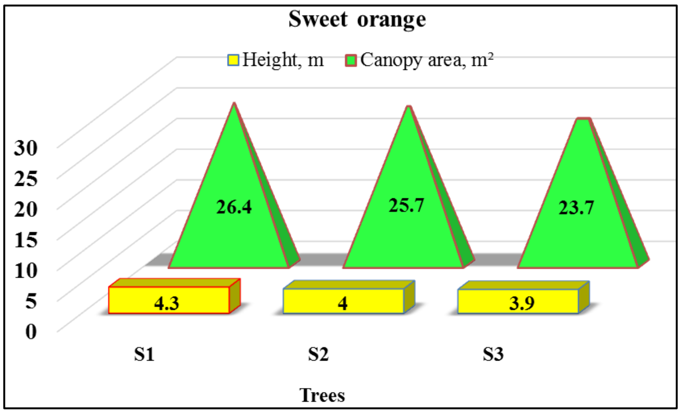

Fig 7: Height and canopy area of trees

3.1 Relative comparison of rainfall, runoff & losses during artificial rainfall simulation on sweet orange tress

The simulated rains were applied on S1 plant and observed for about 23 minutes maintaining a consistent supply pressure of about 0.5 kg/cm^2 at inlet end. The applied rains were on an average was of 52.57 mm/hr intensity. The ultimate runoff rates reached remained in the range of about 25 mm/hr after end time of simulated rains

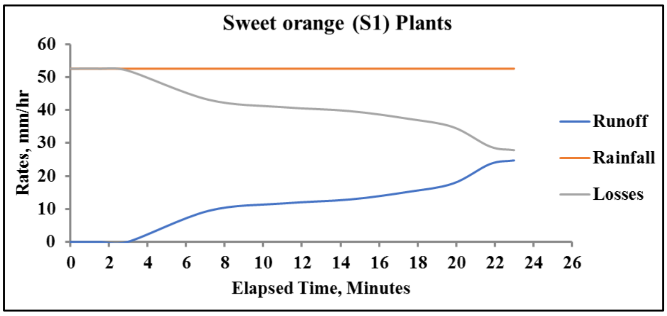

Fig 8: Relationship of rainfall, runoff and losses in sweet orange S1 plant

The simulated rains were applied on S2 plant and observed for about 20 minutes maintaining a consistent supply pressure of about 0.5 kg/cm^2 at inlet end. The applied rains were on an average was of 52.57 mm/hr intensity. The ultimate runoff rates reached remained in the range of 25 mm/hr after end time of simulated rains

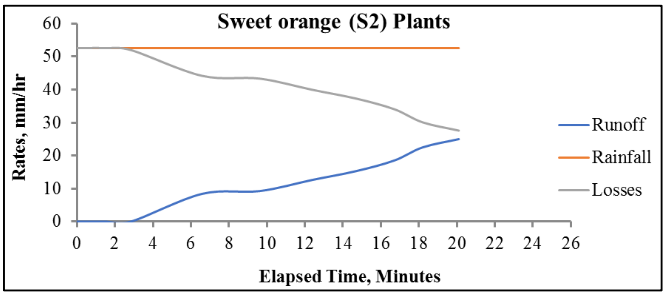

Fig 9: Relationship of rainfall, runoff and losses in sweet orange S2 plant

The simulated rains were applied on S3 plant and observed for about 19 minutes maintaining a consistent supply pressure of about 0.5 kg/cm^2 at inlet end. The applied rains were on an average was of 52.57 mm/hr intensity. The ultimate runoff rates reached remained in the range of 25 mm/hr after end time of simulated rains.

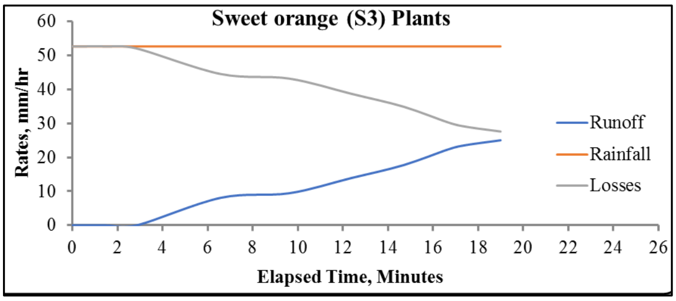

Fig 10: Relationship of rainfall, runoff and losses in sweet orange S3 plant

Looking into spectrum of observed patterns of hydrological components under different sweet orange orchard, an effort was made to understand the causes and factors which are responsible to govern these variations under prevailing domains of input rains and the soil vegetation cover complexes. The major factors were found to be the tree canopy specifically the canopy cover, leaf arrangement and leaf densities on the tree adopted under observation. Higher the plant height and canopy area take longer time to steady the runoff and vice versa. The reason behind this process is canopy cover reduce the kinetic energy of rain drops and plant's root fix the soil through strong bond between root and soil particles (Bochet *et al*., 1998; Gyssels *et al*., 2005) [2, 6]. More canopy area results in lower runoff volume because the runoff path becomes more tortuous which slow down the runoff and allowing more time to infiltrate the water in the soil (Thurow *et al*. 1986) [14].

4. Conclusion

A simple economical and adjustable rainfall simulator of 5 m (16.40 ft) vertical height and 1.5 m (4.92 ft) horizontal length was developed to measure the effect of canopy coverage and plant height on runoff generation. The observed rainfall drops were remained well below 0.5 to 0.6 mm in diameter matching with general natural rainfall of this region. While generating so the net pressure at inlet supply end was observed in the range of 0.5 to 1.0 kg/cm^2. It was noticed that initial abstractions as realized from this experimentation remained capable to withheld all the applied rains for initial 3 to 5 minutes durations depending upon the tree canopy and its vegetative parts.It happened owing to dryness of tree components including leaves and its barks. Predominantly it was concluded that increase in plant height and canopy area reduce the runoff and it's time to generate from definite area.

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