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Design of Demonstration Plots and their Equipment for Measurement of Runoff and Sediment Quantification

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ABSTRACT

Six runoff plots are constructed at MARDI Agrotechnology Park, Cameron Highlands measuring 2.5 by 10.0 m to measure runoff and sediment from a 5% slope. To each plot was fixed a small 3-ℓ tipping bucket, constructed using an acrylic sheet inserted into an acrylic box. The bucket was connected to a plastic stilling basin before attaching it to the runoff plot. The size of the tipping bucket was determined based on the desired area of the plot, maximum rainfall intensity and expected runoff and also the diameter of the runoff water conveyor pipe which in turn will depend on the head of water. The bucket constructed could accommodate a maximum flow of 19.5-ℓ/min in the area with a tipping interval of 9.2 sec per cycle.

Keywords: Runoff plots, tipping bucket, sediment, erosion

INTRODUCTION

MARDI Agrotechnology Park, Cameron Highlands is a popular visiting site among researchers and students. This is because this station has been in existence since 1925 and has been the testbed for several research studies. In 2003, besides its research activities the station began giving increasing emphasis to agro-tourism. One of the agrotechnology components of the station is an area with plots with a tipping bucket system.

According to Hudson (1993), one of the best uses for runoff plots is demonstration, where the purpose is to demonstrate known facts. Another use is to obtain data for constructing or validating a model or equation to predict runoff or soil loss.

The principle of the tipping bucket is commonly used in rain gauges (World Meteorological Organisation 1961). Big capacity single buckets are not useful because they cannot measure low flow rates (Ahmed and Chin 1997).

An acrylic tipping bucket system was constructed in Japan International Research Centre for Agricultural Scinces (JIRCAS) at Ishigaki by Gesite (1997). It was then introduced to MARDI Agrotechnology Park, Cameron Highlands for demonstration purposes. The tipping bucket system for measuring runoff rates was established in MARDI in 1991. The system was introduced by the Australian Centre for International Agricultural Research (ACIAR) to their counterpart countries. The system consists of a 7-ℓ Polyvinyl Chloride (PVC) tipping bucket with a concrete stilling basin. The methodology and instrumentation for the

measurement of rates of runoff and soil erosion are as described by Ghulam *et al.* (1990).

This paper describes the construction of small runoff plots, installation of a simple stilling basin and the design, fabrication and calibration of a 3-ℓ acrylic tipping bucket system.

MATERIALS AND METHODS

Design, Checking and Fabrication of the Tipping Bucket

The size of the tipping bucket was determined based on the desired area of the plot, maximum rainfall intensity and expected runoff and also the diameter of the runoff water conveyor pipe which in turn will depend on the head of water.

1. Determination of maximum flow:
   Plot area = 25 m^2.
   Maximum rainfall intensity = 0.0012 *m*/min (Tanah Rata data, 1999-2000)
   Expected runoff = 65% of rainfall, due to low infiltration rates of the soils (Wan Abdullah *et al.* 2001)

   Calculation of flow using the rational method:
   $Q = CiA$ (1)
   (Flow = Coefficient of runoff x intensity of rainfall x area of catchment)
   Q = 0.65 x 0.0012 m/min x 25 m^2.
   =0.0195 m^3/min or 19.5 - ℓ/min

   For a 3-ℓ tipping bucket, the flow rate of 19.5-ℓ/min will need a tipping interval as given below:
   Tipping interval = 3 - ℓ/19.5 - ℓ/min x 60 *s* = 9.2 s per cycle.

2. The tipping bucket was made from a 5-mm thick acrylic sheet. It consisted of a rectangular base (0.48 m long x 0.30 m wide), a rectangular divider (0.30 m wide x 0.12 m high) and two triangular sides (0.48 m long x 0.12 m high) (Fig. 1). An adhesive was applied during its fabrication. The volume of one side of the bucket was 0.5(0.24 x 0.12 x 0.30) m = 0.00432 m^3 or 4.32 - ℓ.

3. Minimum outlet diameter:
   Given discharge, Q = 3 - ℓ/9.2 *s*
   = 0.33 - ℓ/*s* or 0.00033 m^3/s
   Area, A = Πr^2 (2)
   Velocity, V = $\sqrt{2gh}$ (3)
   where g = gravitational constant, 9.81 *m/s*
   h = head of water = 0.1 *m*

$$Q = AV \quad (4)$$
$$Q = \Pi r^2\sqrt{2gh} \quad (5)$$
$$r^2 = Q/(\Pi\sqrt{2gh}) \quad (6)$$
$$= 0.00033/(3.14 \times 1.41 \times 9.81 \times 0.10)$$
$$r = 0.009\ m$$

This setup used a 0.035 *m* diameter PVC pipe.

Other major parts of the tipping bucket systems were:

4. A 4-digit mechanical counter (Togoshiseiki Co. Ltd. Japan). It indicates the the number of times the bucket has been tipped with a specified volume.

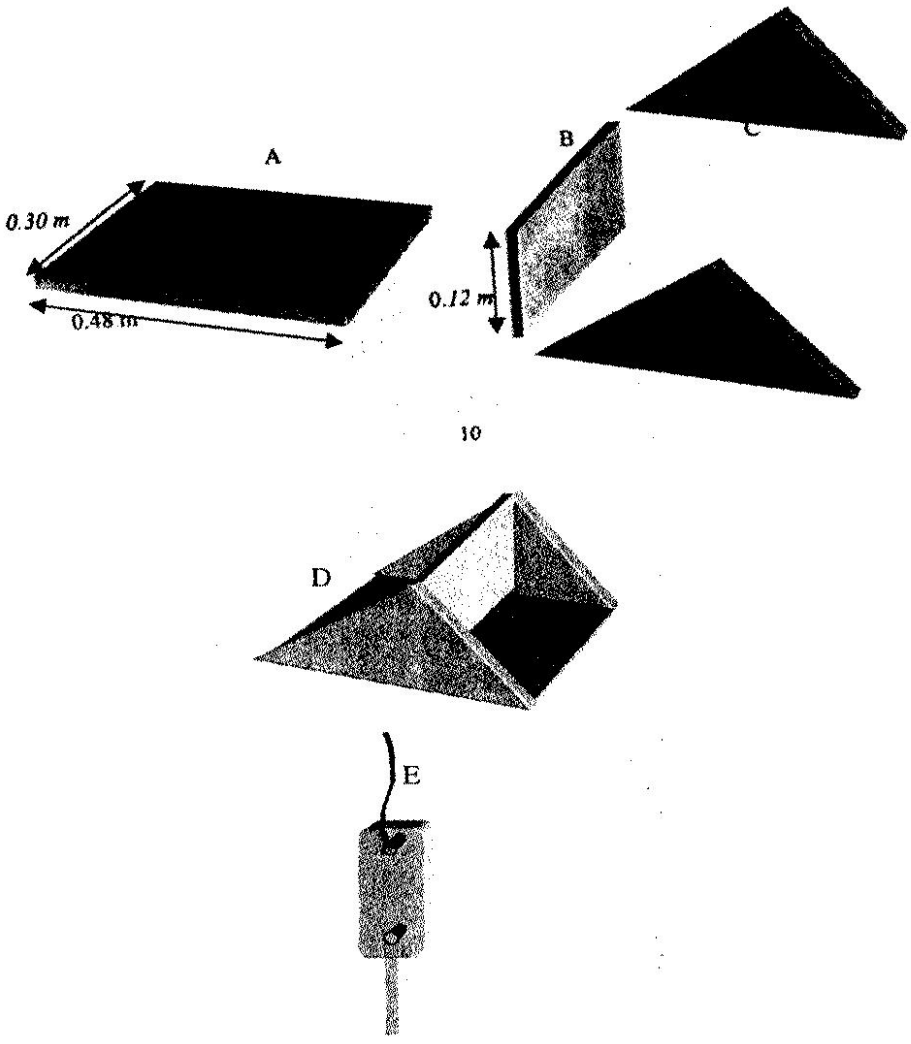

Fig. 1: Main parts of a tipping bucket

A. Rectangular base
B. Divider
C. Triangular side
D. Tipping bucket without frame
E. Tally counter level with thin wire

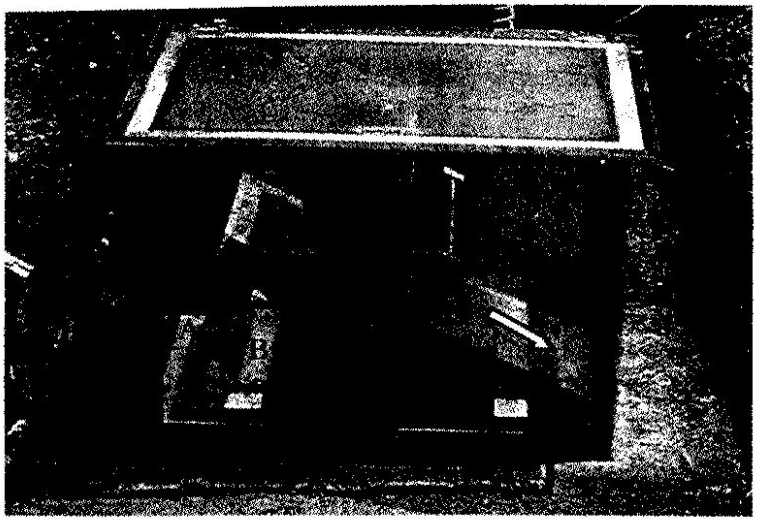

Plate 1. Tipping bucket system
(A= gap for water outlet, B=adjustable wooden stopper, C=flow direction)

5. The tally counter level was fabricated from an aluminium bar connected to the mechanical counter through a thin wire. The opposite end of this tally counter overlapped a bolt attached to the shaft of the tipping bucket.
6. The shaft and axle: the shaft was made from an aluminium bar attached to the frame of the tipping bucket and to the tipping bucket itself. The axle was a stainless rod, 7.0 mm in diameter.
7. The adjustable stopper was made from wood material (43 mm high x 43 mm wide x 410 mm long) and could be adjusted for a desired volume of runoff (Plate 1).
8. The runoff water conveyor serving as an outlet from the stilling basin to the tipping bucket was via a 3.5 mm diameter PVC pipe.
9. The frame of tipping bucket was constructed using aluminium bars (32 mm wide x 3 mm thick) .
10. An acrylic sheet was used for walling and roofing . The bucket could be accessed through a door on the roof. The base was left open for the water to flow out (Plate 1).

Calibration

The tipping bucket in this study was calibrated in the following ways:

1. Measured volume versus horizontal distances of adjustable stopper. The fixed volume of water was tested against location of the stopper.
2. Volume versus time. Accuracy was tested on slow and rapid runoff flow.

Field Setup

The plot is situated in front of the MARDI buildings at Cameron Highlands, providing easy access for visitors. It is also located behind the current meteorological station, which has a tipping bucket rain gauge. The tipping bucket was fixed in an acrylic box of 0.62 m length x 0.53 m width x 0.39 m height with

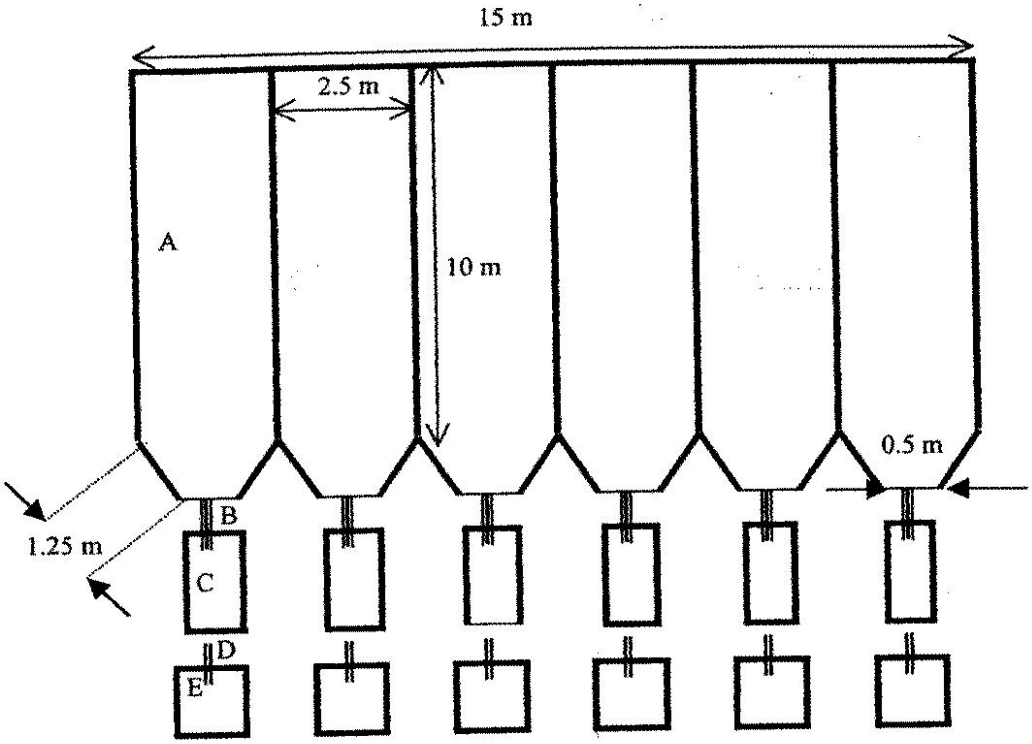

Fig. 2: Plot layout
A = plot, B = clay ditch, C = sediment trap, D = PVC pipe, E = tipping bucket

Plate 2. Runoff plots at MARDI Cameron Highlands
(A=wooden planks, B=clay ditch, C=plastic basin, D=PVC pipe, E= tipping bucket in box)

a total weight of 10 kg.

The plot setup was on a 5% slope soil which was levelled to obtain a uniform slope. The soil was then compacted using a light bulldozer as practised by farmers. The area of 15 m width and 10 m length was then divided by planks into six plots

TABLE 1
Accuracy of slow and high flow of tipping bucket

Parameter	Left bucket	Right bucket
Volume of water measured, ℓ	2.60	2.56
Average volume per tip, ℓ	2.58	
Volume at slow flow (4.14-ℓ/s), ℓ	2.67	2.64
% error	= (2.67-2.58)/2.58 x 100 = 3.49	= (2.64-2.58)/2.58 x 100 = 2.33
Accuracy for each side, %	= 100 - 3.49 = 96.51	= 100-2.33 = 97.67
Accuracy for tipping bucket, %	97.09	
Volume at fast flow (15L/s), ℓ	2.76	2.85
% error	= (2.76-2.58)/2.58x100 = 6.98	= (2.85-2.58)/ 2.58x100 =10.47
Accuracy for each side, %	= 100 - 6.98 = 93.02	= 100-10.47 = 89.53
Accuracy for tipping bucket, %	91.28	

of 2.5 m width and 10 m length (Plate 2). A clay ditch was installed at the end of each plot and connected to a plastic sediment trap (0.40 m width x 0.40 m depth x 0.90 m length) for measurement of soil loss; the trap was covered by an acrylic sheet. Discharge from the sediment trap flowed into the tipping bucket via a 3.5 mm PVC pipe located immediately above the tipping bucket (Fig. 2). The count of the tips was recorded by a counter. A datalogger can also be used to count the number of tips via a magnetic sensor.

RESULTS AND DISCUSSION

Calibration was by moving the stopper horizontally and using water flow from a tap water. The minimum volume of the left bucket was found to be 1.35-ℓ and 1.29-ℓ for the right bucket while the maximum volume was 3.96-ℓ and 3.32-ℓ for left and right buckets respectively. For a volume of 3-ℓ water, the stopper should be located at 0.17 m from the middle of the tipping bucket for both left and right buckets.

The accuracy test was done on a tipping bucket which could retain water of 2.60-ℓ and 2.56-ℓ in the left and right buckets respectively. The average volume for the bucket was 2.58-ℓ. Accuracy test was determined using the formula:

% error = (volume of water in tipping bucket for respective flow rate – 2.58)/ 2.58 x 100
% accuracy for each side = 100 - % error
% accuracy for tipping bucket = (% accuracy for both sides)/2 (7)

The test showed that tipping bucket accuracy at slow flow was 97.09%, while at rapid flow, it was 91.28% (Table 1).

It was not easy to get an exact flow of 19.5-ℓ/min to test the tipping interval for the 3-ℓ tipping bucket. Therefore several flow rates were tested against the average time taken for one cycle (average of six tilt actions). The relationship between duration Y, in seconds and flow rate, X-ℓ/min is

$$Y = 144.99X^{-0.88} \qquad R^2 = 0.96 \qquad (8)$$

From equation 8, the time taken for one cycle was 10.6 *s*. This value is about 1 *s* different compared to the value of 9.2 s. In the field, this situation can be accepted because of the turbulence of the flow and the fact that the flow contains suspended sediments as well.

From this setup, the runoff rate at a daily, weekly or monthly basis can be obtained from the total amount of tips recorded. To get a runoff rate for each rainfall event, the tipping bucket is attached to a data logger system, which can be compared to the existing tipping bucket rain gauge. The sediment trap should be big enough to trap the sediment and decrease the turbulent water flow. The current setup will only trap the bedload, while the suspended load is carried away through runoff to the drainage system.

CONCLUSION

The use of a 3-ℓ an acrylic tipping bucket system with manual counter and data recorder to measure runoff is a simple method of measuring and calculating runoff. The system can measure runoff volume up to 97% accuracy. Runoff rates can be easily calculated from the data recorder. The coarser sediment settles down easily and is trapped in the deep and long stilling basin.

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REFERENCES

AHMED, A. H. and K.O. CHIN. 1997. Design and calibration of tipping bucket system for field runoff and sediment quantification. *J. Soil and Water Conservation* **52(6):** 437-443.

Gesite, B. 1997. Introduction of low cost runoff mechanical recorder in monitoring runoff under sugarcane with various cover crops for erosion control. JIRCAS Okinawa, Japan progress report. Vol. 6.

GHULAM, M. H., C. CIESIOLKA, C., W.Y. WAN ABDULLAH, N. ABDUL WAHAB, N. and M.

MOHD ZAIN. 1990. Methodology and instrumentation for the measurement of rates of runoff and soil erosion. Paper presented at *the Malaysian Soil Science Society Conference*. Malacca.

HUDSON, N. W. 1993. Field measurement of soil erosion and runoff. FAO bulletin no. 68. pp. 25-52.

WAN ABDULLAH, W.Y., R.B. SALAMA and B.Y. ANMINUDDIN. 2001. Impacts of agricultural activities on soil erosion and water resources in the Cameron Highlands. In *Agrochemical Pollution of Water Resources*. ACIAR proceedings No. 104. ACIAR Canberra. pp. 26-31.

WORLD METEOROLOGICAL ORGANIZATION. 1961. Guide to meteorological instrument and observing practices. W. M. O. – No. 8T P3