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An outdoor portable rainfall erosion laboratory

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ABSTRACT A trailer mounted rainfall simulator for infiltration and erosion research has been built and tested. Rainfall is applied continuously through a series of drop forming needles. The simulator allows for a wide range of intensities, from near zero to approximately 200 mm h^{-1}. In conjunction with the simulator, an automatic microrelief profilimeter is used to measure soil surface characteristics. This instrument automatically scans points on a 1 cm by 5 cm grid spacing to measure soil surface elevations with a vertical resolution of 1 mm over a 25 cm range. Also, associated with the laboratory is a density measuring apparatus which continuously records sediment concentrations in runoff water.

Laboratoire extérieur transportable pour l'étude de l'érosion par la pluie

RESUME Un simulateur de pluie monté sur rails, en vue de recherches sur l'infiltration et l'érosion a été mis au point et testé. La pluie est produite de façon continue grâce à une série d'aiguilles produisant des gouttes. Le simulateur, peut être utilisé pour une large gamme d'intensités depuis presque zero jusqu'à environs 200 mm h^{-1}. On associe à ce simulateur un releveur de profil automatique pour l'étude du microrelief. Cet appareil relève des points sur un réseau à mailles de 1 cm par 5 cm en déterminant la cote du sol avec un pouvoir de résolution de 1 mm pour mesurer des différences de niveau de 25 cm. On combine également avec ce laboratoire un enregistreur de densité qui suit de façon continue la concentration en sédiments de l'eau de ruissellement.

INTRODUCTION

Rainfall simulators have been used for many years in erosion and infiltration research. Many different simulators of different sizes with varying characteristics have been constructed (Bubenzer, 1979). Generally, each can be characterized in one of two ways: continuous or intermittent rainfall application. The rainulator (Meyer & McCune, 1958) with which much basic erosion research is conducted is of the intermittent type. This type normally has energy characteristics similar to natural rainfall but applies water at a very high rate for a short time period followed by a period of no rainfall allowing infiltration capacity to partly recover. Frequently, simulators applying rainfall continuously have poorer energy relations because low pressure drop formers are used rather than nozzles.

In the past, most soils and cultural data have been generic, for example, "conventionally tilled corn, 30 days after planting on Barnes silt loam". For use in mathematical simulation of physical processes, these data are not adequate because numbers reflecting the various conditions are not specified.

Runoff and soil loss data from most erosion plots are collected by a laborious subsampling procedure. Although this method is usually satisfactory, sampling intervals are frequently too large to represent adequately the dynamic processes that are occurring, especially during the early part of a runoff event. Simulators have been constructed and used in the laboratory where instrumentation is available to measure dynamic processes adequately. However, under these conditions, soil is moved into the laboratory in a disturbed condition, not truly representing field conditions.

Described here is a mobile laboratory consisting of three basic instruments designed to provide quantitative measures of surface roughness and continuous measures of runoff and sediment concentration during a simulated continuous rainfall event. The three basic instruments are a rainfall simulator, a microprocessor controlled profilimeter, and an instrument capable of continuously measuring densities of flowing streams. Other common instruments for measuring soil physical characteristics and runoff rates and volumes also may be included. An example of the type of data that are obtained from this ensemble is presented.

RAINFALL SIMULATOR DESIGN

The rainfall simulator was developed considering four principal objectives: (a) continuous rainfall application; (b) rainfall intensities ranging from near zero to 200 mm h^{-1}; (c) drop size distribution permitting good energy relations compared with natural rainfall; and (d) an easily portable system. In addition, the entire system, as shown in Fig. 1, is "self contained" such that it can be operated at remote sites. The design of the rainfall system is a modification of that developed by Hamon (1979) and reported by Brakensiek *et al.* (1979).

For ease of handling, the simulator uses four identical modules. Each module is 0.61 m by 0.91 m comprised of two separate compartments as shown in Fig. 2. Water is supplied to the drop formers from the top compartment and air to control drop size is added to the bottom compartment. The drop formers are stainless steel capillary tubes having inside diameter of 0.69 mm. The plates separating the compartments are made from polyvinyl chloride (PVC) plastic. Water supplied to the top compartment is pumped from the water supply tank through either one of two flow

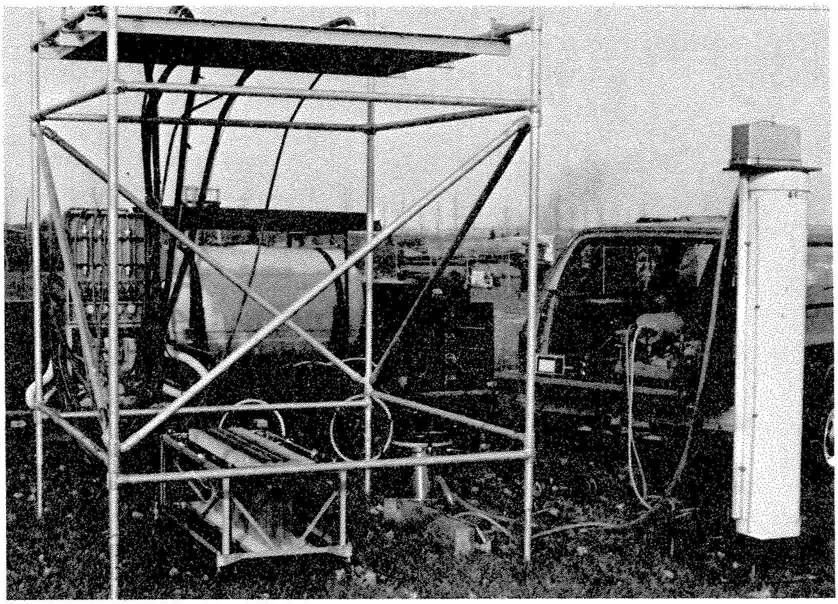

Fig. 1 The portable laboratory ensemble showing the simulator and associated equipment, the profilimeter, and the soil-water density measuring equipment.

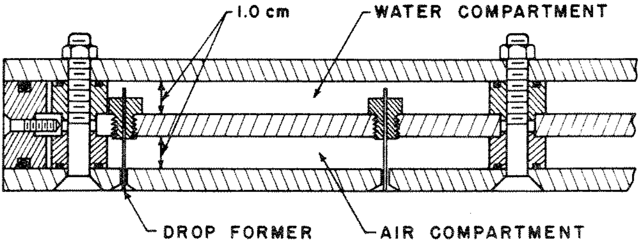

Fig. 2 Rainfall module cross section.

meters each capable of measuring flow rates to an accuracy of 2%. One flow meter is used for intensities of 0-30 mm h^{-1} while the other is used for intensities of 0-200 mm h^{-1}. Needle valves are used to control the flow of water to each of the modules.

The bottom compartment is supplied with air obtained from the discharge side of a common shop vacuum cleaner. Air is forced from the bottom compartment around the drop forming needles that are placed in countersunk holes, 7.6 cm apart, on the bottom plate of the module. The static pressure of the air system is controlled by butterfly valves capable of regulating pressures of up to 150 mm of water. Increased air pressure increases the air velocity past the drop forming needles resulting in smaller drops.

The module support frame is constructed using aluminium pipe, 31.8 mm in diameter. Screw adjustments for levelling the module support frame are located at the bottom of the aluminium legs. The frame can be assembled and dismantled easily or moved a short distance by two persons while assembled.

The rainfall modules are placed 2 m above the ground. This is a compromise between practicability and satisfactory kinetic energy values. Brakensiek *et al.* (1979) reports that the kinetic energy of simulated rainfall at intensities up to 101.6 mm h^{-1} averaged about 83% of the energy of natural rainfall as reported by Laws & Parsons (1943) with best reproduction at 25.4 mm h^{-1}. Kinetic energy was calculated by the method developed by Wischmeier & Smith (1958) using the actual simulator drop size distribution.

The simulator is capable of producing drops with a wide range of sizes by varying the air pressure in the lower compartment of the modules. Figure 3 shows the drop size distribution after Laws & Parsons (1943) compared with the simulator distribution for a rainfall intensity of 101.6 mm h^{-1}. Note that the range of drop sizes is narrower for the simulator, but that the mean is closely matched. This narrower distribution combined with the short drop fall (2 m) accounts for most of the reduced kinetic energy from the simulated rainfall. However, the energy comparisons do not consider a slightly increased value that results from the drops leaving the drop former with an initial velocity greater than zero due to the discharge of air around the drop former.

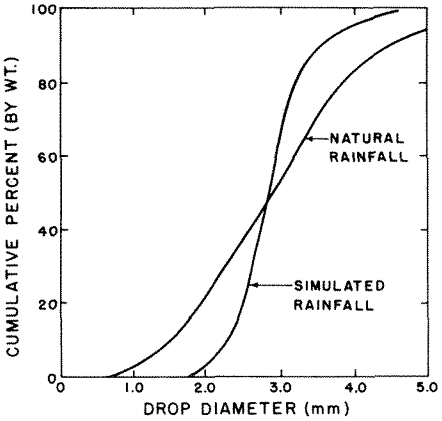

Fig. 3 Drop size distribution for simulated and natural rainfall at 101.6 mm h^{-1} intensity.

Runoff is collected from the test plot which is 91.4 cm by 152.4 cm by placing a frame around three sides of the plot. The frame is driven about 25 cm into the soil with 15 cm remaining above the soil surface. A steel cutoff wall is driven 30 cm into the soil on the downslope side with the upper edge about even with the soil surface. A collection trough is attached to the cutoff wall. Runoff water is transferred to the measuring tank via a vacuum system. A part of the runoff is also abstracted from the trough and pumped through density measuring equipment and returned to the trough. The runoff measuring storage tank is a PVC cylinder, 30.5 cm in diameter, 180 cm tall with a stage height recorder mounted on top.

All of the simulator equipment when disassembled is placed on a small transport trailer suitable for towing by a small truck.

In addition to the simulator apparatus, the trailer also contains a 1100 litre water supply tank and a 5000 W, 110 V, gasoline engine-driven electric generator. The generator is used to power the water supply pump, the two vacuum cleaners, and the pump supplying water to the density measuring device.

PROFILIMETER

Soil surface roughness is measured by a microprocessor controlled automatic profilimeter (Radke *et al.*, 1981). This instrument is capable of measuring over 300 surface elevations in less than a minute with a vertical resolution of 1 mm over a 25 cm range. It is battery operated for remote field operation by two people. Data are automatically recorded on magnetic tape cassettes that are easily read into a computer system.

The profilimeter measures 312 surface elevations with three rows of sensing rods of equal length. The rows are spaced 5 cm apart while the rods are spaced 1 cm apart within the row. A 12 V d.c. electric motor powers four screws that move the platform containing the sensing rods that open individual electric contacts upon touching the soil surface. As the platform is raised, a microprocessor scans all the contacts several times before the platform moves 1 mm. When a sensing rod leaves the soil surface, the contact closes and the microprocessor senses the state change and stores the platform position in an associated memory location. When all the data are stored, the memory is transferred to magnetic tape which is read by a computer.

SOIL-WATER DENSITY MEASUREMENT

Continuous runoff density is measured using a Dynatrol* instrument. This instrument consists of a density cell, a converter, a strip chart recorder, and a small paddle pump. The pump draws the runoff from the collection trough and discharges it through the density cell and back into the collection trough.

The runoff passes through a U-tube inside the density cell that is mechanically vibrated by a drive coil. The drive coil vibrates the U-tube at a constant frequency of varying amplitude depending on the mass of the fluid contained in the tube. When the effective mass in the U-tube increases, the amplitude decreases and conversely, when the effective mass decreases, the amplitude increases. Changes in vibration amplitudes are sensed by a pick-up armature and coil arrangement as changes in an alternating current voltage which is the cell output signal. The signal is fed into the solid state converter where it is changed into a millivolt signal compatible with common electronic

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* *Trade names and company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product listed by the US Department of Agriculture.*

recorders. The instrument is capable of measuring soil concentrations up to 200 000 mg l^{-1} with an accuracy of ±0.0005 specific gravity units.

The density is measured independent of flow rate through the cell but care must be taken to ensure that the constant rate is high enough so that real changes in density are not damped out in the averaging process by too slow a pumping rate. On the other hand if the pumping rate is too large, air may be drawn into the cell causing large errors in the output signal. The calibration curve was derived for the density cell using materials having particle densities ranging from 2220 to 7140 kg m^{-3}. The curve was found to be independent of particle size as long as the particles remain entrained in the fluid.

EXAMPLE OF USE

To illustrate the use of the laboratory, data are shown from a simulator run on a tilled surface. The objective of the experiment was to determine the effect of soil surface conditions as influenced by tillage on depressional storage and infiltration. Soil losses were also measured for future analyses. In the past, most soil tillage and cultural data have been generic, that is, numbers were seldom used to describe a condition. Instead, descriptive terms such as conventionally tilled, ploughed, or time since planting, etc. were used. Obviously, these are not sufficient for mathematical modelling purposes so new data are necessary for verification of infiltration-erosion-tillage models.

In addition to the data obtained directly from the laboratory components, auxiliary soil data were obtained to determine the parameters necessary for simulation of infiltration and erosion processes. These data included initial soil water content, saturated hydraulic conductivity, soil water potential, bulk density, and particle size distribution by layers in the soil profile.

For this experiment, rainfall was applied at the rate of 63.5 mm h^{-1} for 2 h. This duration was selected so that the runoff rate would reach equilibrium for the tillage treatment. The total kinetic energy applied under these conditions is about 1.174 MJ ha^{-1} mm^{-1}, which is about 85% of that from natural rainfall based on Laws & Parsons (1943) data. The tillage treatment for this particular run was ploughed and disked and free from surface residue.

Before and after the simulator run, the profilimeter was used to measure the surface configuration. Figure 4 shows the surface profile plotted by a computer for the surface condition after the simulator run. The broad depression running across the rows near the centre is the tool mark down which the runoff flowed. A measure of roughness has been defined by Allmaras *et al.* (1966) as the standard error among heights. When oriented roughness such as from slope and tool marks has been eliminated, the remaining value is termed random roughness. Before the simulator run, random roughness as calculated from profilimeter

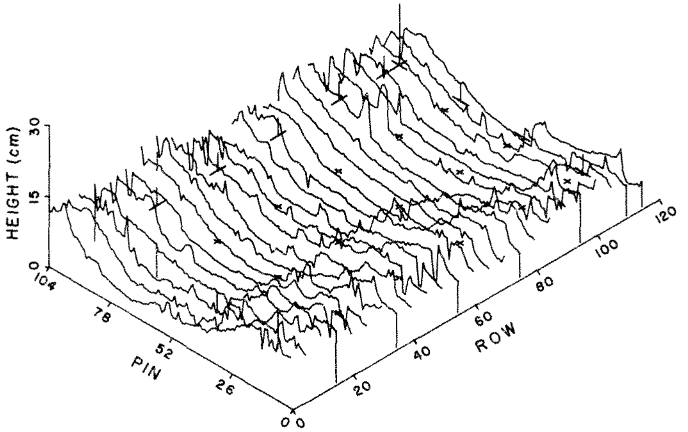

Fig. 4 Microrelief of ploughed and disked plot after 127 mm rainfall application.

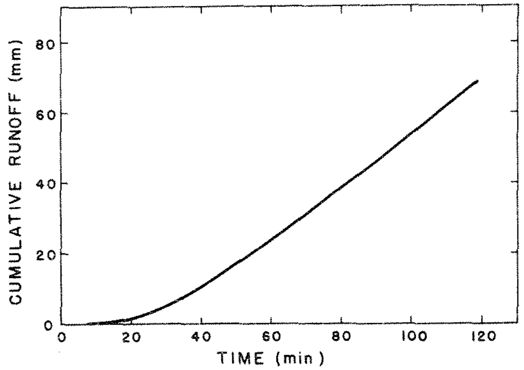

Fig. 5 Cumulative runoff from ploughed and disked plot.

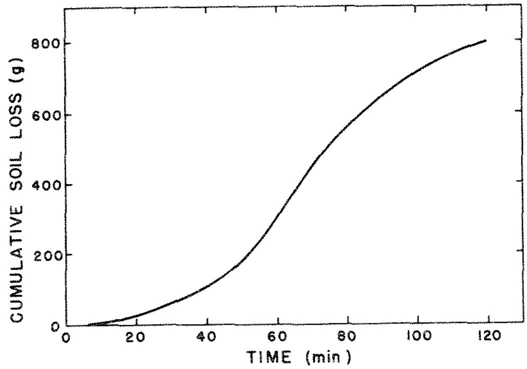

Fig. 6 Cumulative soil loss as calculated from soil-water density measuring equipment and runoff hydrograph.

measurements was calculated to be 2.05 cm and after, 0.79 cm.

Cumulative runoff with time for this run is shown in Fig. 5. This figure was obtained from the trace of the stage-height recorder on top of the runoff collection tank. Runoff began at about 8 min and reached its equilibrium rate at about 80 min. For rougher soil surface conditions, runoff would reach its equilibrium rate at a later time. For this run the equilibrium runoff rate was about 0.76 mm min^{-1} and the total plot runoff was 69 mm.

The cumulative soil loss with time for the run is shown in Fig. 6. This figure was derived by converting the millivolt trace produced by the Dynatrol to soil-water mixture density and then multiplying by the runoff rate and accumulating over short time periods. The cumulative soil loss for this run was about 800 g corresponding to a field loss of 5750 kg ha^{-1}.

On a plot of this size, measured sediments are the result of detachment by raindrop impact rather than by concentrated runoff flow. In this case transport capacity is not limiting as it would be under field conditions where channel or rill flow would develop. The data shown in Fig. 6 indicate that an equilibrium soil loss rate is not obtained even after a rainfall of 2 h duration for this particular plot. Soil loss rate begins decreasing at about 70 min. As this time most of the loose soil particles on the soil surface have been depleted and runoff rate has reached equilibrium.

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