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THE AKRON USDA-AGRICULTURAL RESEARCH SERVICE PORTABLE BOOM-MOUNTED RAINFALL SIMULATOR

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ABSTRACT

A rainfall simulator was constructed with improved portability, water storage and ease in changing nozzles. The rainfall simulator is comprised of water tanks and a rotating turret and boom attached at the rear of a flat-bed trailer. The boom is rotated to one side of the trailer for applying water to plots and positioned over the trailer and tanks for road transport. Interchangeable frames that hold the nozzles are suspended from the end of the boom. Typical set up time is 5 min. The simulator can apply water at rates up to 100 mm/hr (4 in./h) on an area of 40 m^2 (430 ft^2) for at least 90 min before refilling is needed.

INTRODUCTION

Rainfall simulators (RS) have been used extensively to conduct infiltration, surface water runoff and soil erosion research during the last few decades. Many types of RS have been developed that differ by method of water application, portability, size of wetted area, and other features (Bubenzer, 1979). Water has been applied with various types of nozzles that can be held stationary or mounted on moving booms. The objective was to build a rainfall simulator that could be set up and operated by one person with high portability, sufficient water storage, quick set up time, and ease in changing nozzle arrangements.

Shelton et al. (1985) developed a unique continuous-application variable-rate RS with nozzles arranged in a square array. Application rate is varied by using air injection to displace some of the water flow just above each nozzle. The most significant aspect of air injection is that drop sizes decrease as the application rate decreases, which is also characteristic of natural rainfall. When air is injected, application rate decreases and nozzle pressure increases which reduces drop size. With water only, increasing pressure increases application rates and decreases drop sizes, which is the opposite of natural rainfall. Air injection is also more convenient for changing application rate than changing nozzles or turning them on and off, or by using water diverting techniques such as rotating slotted disks.

AKRON USDA-ARS RAINFALL SIMULATOR

A portable boom-mounted, continuous-application RS was constructed using the basic design developed by Shelton et al. (1985). A 5.5 m (18 ft) long flat-bed trailer was the foundation on which a rotating turret and a 4.6 m (15 ft) boom were mounted to the trailer to hold various spoke-like pipe frames to which the spray nozzle assemblies were attached. The RS is shown in the operating position in figure 1. For transport between field sites, the boom is rotated over the tank and trailer. The RS uses a 4.16 m^3 (1100 gal) tank for self-contained water storage. A second tank can also be added to increase storage to 5.67 m^3 (1500 gal). A separate 7.56 m^3 (2000 gal) tank trailer is used to haul water to the RS.

Components of the RS framework include the rotating turret, attaching framework, boom and hydraulics. The turret consists of two pieces of IPS-SCH40 pipe with a 101.6 mm (4.000 in.) O.D. inner pipe rotating inside a 114.3 mm (4.500 in.) O.D. outer pipe. The outer pipe is welded to a supporting framework of 127 mm (5 in.) channel steel that is bolted to the main frame of the trailer. The boom consists of two 4.6 m (15 ft) long pieces of 9.84 mm (3 in.) channel steel hinged at the top of the inside turret pipe. A third 2.5 m (8 ft) piece of channel steel was added between the other two pieces of the boom for added flexure strength. Spacers were positioned and bolted along the boom for stability.

Two nozzle and pipe frames are currently being used. One frame consists of nine nozzles in a three by three array (fig. 1) with approximately two meter nozzle spacing. The other, which is used for doing sprinkler infiltrometer research, has four nozzles in a two by two array with a 2.5 m (8 ft) enclosure to minimize evaporation and drift (fig. 2). The protective enclosure frame is made of 13.7 mm (0.5 in.) steel electrical conduit with plastic tarp covering the frame. The enclosure consists of two sections, each 1.5 m (5 ft) high, which telescope inside each other to fit on the trailer for transport (fig. 3).

Three hydraulic cylinders are used to: 1) raise and lower the boom, 2) rotate the boom between transport and

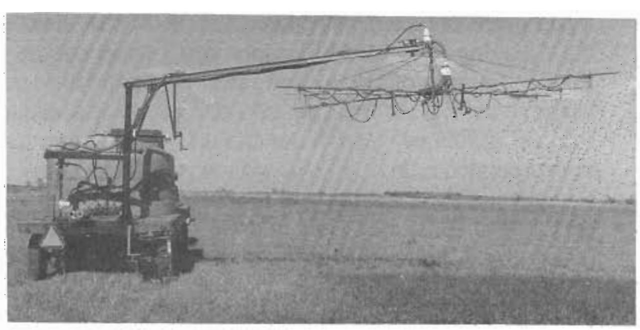

Figure 1–Rainfall simulator with the nine-nozzle frame and the boom rotated in the operating position.

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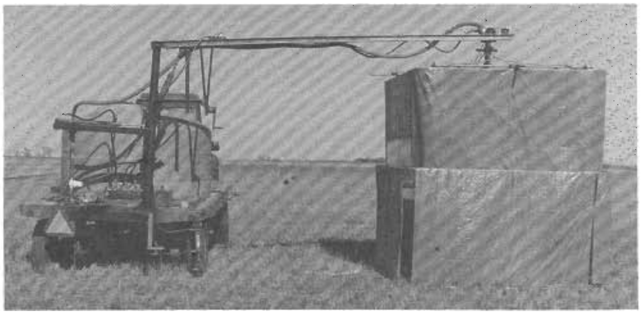

Figure 2–Rainfall simulator with the four-nozzle frame and wind protection enclosure in operating position.

Figure 3–Rainfall simulator with the four-nozzle frame and enclosure in transport position.

operating positions, and 3) as a leveling foot (fig. 3) at the rear, boom-side corner of the trailer. The cylinders are controlled with hydraulic valves at the rear of the trailer. Hydraulic power is provided by a hydraulic circuit (fig. 4) connected to one of the hydraulic connections at the rear of the tractor. The RS frame was designed to have a carrying capacity at the end of the boom of 2220 N (500 lb) force with a safety factor of 2. The nine nozzle frame weighs approximately 445 N (100 lb) and the four nozzle frame and enclosure weigh approximately 890 N (200 lb).

The nozzle frames can be attached to a fixed point at the end of the boom (fig. 1) or to a rolling carriage that rides on top of the boom (fig. 2). The rolling carriage is attached to a cable and pulley system and can move in or out 1.2 m (4 ft) for easier positioning over field plots. The carriage consists of four steel caster wheels and a hanging frame and connection joint that rides between the two pieces of channel steel of the boom.

Water and air are supplied to the nozzle with 16 mm (5/8 in.) rubber garden hose and 9.5 mm (3/8 in.) clear vinyl tubing, respectively. Separate radial manifolds are used for water and air distribution, as suggested by Shelton et al. (1985). Supply lines to the manifolds are 38 mm (1.5 in.) plastic suction hose for water and 19 mm (3/4 in.) rubber garden hose for air.

Nozzles used with this RS are Spraying Systems* Fulljet HH30WSQ. When operated at nozzle pressures of approximately 20 kPa (3 psi), these nozzles produce a full range of drop sizes up to 6 mm (1/4 in.). When operated from a height of 3 m (10 ft) water drop impact velocities are within two percent of their terminal velocities (Shelton et al., 1985). Christiansen's (1942) distribution uniformity coefficients are generally greater than 80% as measured by the author and by Shelton et al. (1985).

Water flow to each nozzle is less than or equal to 6.8 Lpm (1.8 gpm). Application rates of 50 to 100 mm/hr (2 to 4 in./h) are obtained with these nozzles. Other nozzles in the Spraying Systems Fulljet HH-WSQ series can be used for other ranges of application rates. When the nine nozzle frame is used, a second 1.51 m^3 (400 gal) tank is added for 5.67 m^3 (1500 gal) total water storage which allows the RS to be operated at least 90 min without refilling.

Each nozzle assembly was modified by inserting a piece of 6.3 mm (0.25 in.) O.D. plastic tubing that fit tightly inside the 9.5 mm (3/8 in.) air inlet hose barb, which is shown in figure 5. This piece of tubing has a 3 mm (0.12 in.) inside diameter and provided for better air injection by having a greater pressure gradient at the point of injection. Greater pressures in the air lines reduce the risk of water migrating up the air lines and interfering with air flow. Without this alteration, water sometimes moved up some of the air lines, stopping air flow entirely in those lines and forcing all of the air to the other nozzles.

Water is pumped with a 250 W (1/3 hp) 120 V AC water pump powered by a gasoline-powered electrical generator that is carried on the trailer. A vertical, tapered-tube and float type 1.91 Lps (30 gpm) capacity flowmeter and gate valves are used to monitor and control water flow. Air is supplied with a 3.7 kW (5 HP) gasoline-powered air compressor and tank, also carried on the trailer. The air compressor supplies up to 3.8 Lps at 276 kPa (8 cfm at 40 psi). A separate tapered-tube and float, 5 Lps (10.5 cfm) capacity flowmeter and valves are used to monitor and control air flow.

OPERATION

The Akron USDA-ARS rainfall simulator works well for watering 4 m (13 ft) square plots with the nine nozzle frame and 1.5 m (5 ft) square infiltration frames with the four nozzle frame and enclosure. The slightly larger 2.5 m (8 ft) enclosure allows the soil outside a smaller infiltration frame to be watered similar to a double-ring infiltrometer, so that more accurate infiltration values are measured. A vacuum extraction system similar to one developed by Kelso (1982) is used to remove any non-infiltrated water.

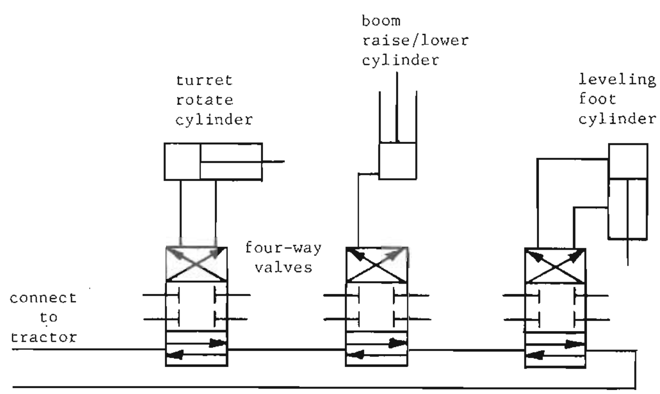

Figure 4–Closed-loop hydraulic circuit used to power the rainfall simulator.

*The mention of tradenames or commercial products does not constitute their endorsement or recommendation for use by the USDA-Agricultural Research Service.

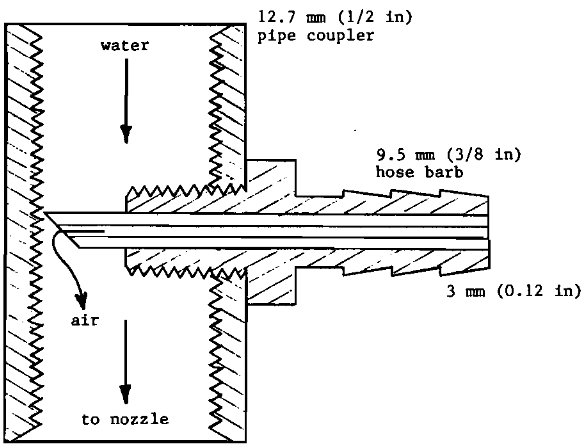

Figure 5–Air injection connection showing the plastic tubing inserted inside the air line hose barb.

The water is collected in a tank, and the volume of collected runoff water over time is measured.

The nine nozzle frame without an enclosure works satisfactorily in winds up to 16 km/h (10 mph) by using the rolling carriage and rotating the boom to position the nozzle frame to compensate for wind drift of the water drops. Typical time for one person to setup over a plot is 5 min and movement to adjacent plots is 3 min. One improvement planned for the RS is to add a hydraulic cylinder and cable system for raising and lowering the lower half of the four nozzle enclosure.

Summary

A rainfall simulator was constructed based on the existing design of Shelton et al. (1985) but with new features to improve portability, air injection, water storage and easier interchanging of nozzle arrays for different research uses. It consists of a flat-bed trailer carrying water tanks for on-board water storage and a rotating turret and boom constructed of pipe and channel steel that is attached to the rear of the trailer. The boom is rotated to one side of the trailer for applying water to plots and positioned over the trailer and water supply tanks for road transport. Hydraulic cylinders are used to control the boom with hydraulic power provided by a tractor that also pulls the trailer. Interchangeable spoke-like frames that hold the nozzles are suspended from the end of the boom. The simulator can apply water at rates up to 100 mm/h (4 in./h), 1 Lps (16 gpm) with the 3 x 3 nozzle array for at least 90 min before refilling is needed.

A nine nozzle (3 x 3) array is used to water 4 m (13 ft) square plots and a four nozzle (2 x 2) array with a wind-protection enclosure is used as part of a sprinkler infiltrometer. The enclosure also fits on the trailer for transport. Better positioning of the nozzles over the plots is possible by rotating the boom and by using a rolling carriage that rides on top of the boom and holds the nozzle frames. Water can be applied in winds up to 16 km/hr (10 mph) without a wind-protection enclosure. Typical time for set up is 5 min and movement to adjacent plots is 3 min. A gasoline-powered air compressor and generator are carried on the trailer to provide air and electricity for the water pump, respectively.

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