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Field Evaluations of Irrigation Systems: Solid Set or Portable Sprinkler Systems[1]

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Introduction

This bulletin describes techniques for measuring operating pressures, water application rates and uniformity during field evaluations of solid set or portable sprinkler irrigation systems. These irrigation systems typically use groups of impact or gear-driven sprinklers which operate at the same time to sprinkle water onto the soil or crop canopy. Sprinkler spacings are relatively close so that overlap between them increases the uniformity of water application.

The techniques presented do not apply to self-propelled irrigation systems such as center pivot, linear move, or traveling gun systems. Nor do they address single sprinkler systems such as large guns or small individual lawn sprinklers. The unique geometries of self-propelled and individual sprinkler systems require other procedures to measure application rates and uniformities of water application.

Solid set sprinkler irrigation systems are those in which sprinklers, with their assorted riser, lateral, and manifold pipes, are placed in a regular pattern over the entire irrigated area. All of the sprinklers may be operated at once, or the crop may be irrigated in zones by operating only a portion of the sprinkler laterals at a time.

Solid set sprinkler systems may be permanent, in which case laterals and manifolds are typically constructed of buried PVC plastic pipe. This is common in many Florida citrus, nursery, strawberry, and ornamental fern production systems and in lawn and landscape irrigation systems. Alternatively, solid set sprinklers may be set in place only during a crop growing season. Sprinklers are then typically mounted on risers above portable aluminum pipelines which are placed on the surface. Laterals may be fed by either portable (typically aluminum) manifolds placed on the soil surface or permanent (typically PVC) buried manifolds. These systems are common for many Florida vegetable, tobacco, and turf crops.

In portable set sprinkler irrigation systems, the sprinklers and associated pipelines are temporarily set up and operated for each irrigated zone. They are then

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moved to a new zone for another irrigation. These systems are used to irrigate several zones; thus, they are designed so that all zones can be irrigated before the first zone needs to be re-irrigated. Because these systems are portable, less pipe and fewer sprinklers must be purchased as compared to solid set systems. However, labor requirements are normally much greater than for solid set systems. The specific system used normally depends on the relative availability of capital versus labor.

Both the solid and portable set sprinkler systems described here use sprinklers that are regularly spaced, typically in square, rectangular, or triangular patterns. The individual sprinkler spacings and discharge rates determine the average irrigation application rate. Many additional factors, including operating pressure, changes in elevation, friction pressure losses, wind, and individual sprinkler characteristics affect the uniformity of water application within an irrigated zone.

The specific objectives of this publication are to present techniques (1) to measure operating pressures, (2) to measure application rates, and (3) to measure the uniformity of water application under field conditions for existing solid set or portable sprinkler irrigation systems. Knowledge of these three factors and changes in their magnitudes over time is important to determine the causes of deficiencies in application rates or uniformities observed. This information is also needed to efficiently and effectively manage sprinkler irrigation systems. Field evaluations should be conducted at least annually to reveal changes which require system maintenance or repair.

Measuring Operating Pressures

Always operate sprinklers within the manufacturer's specified pressure ranges. Sprinkler effectiveness is reduced by operation at either excessively high or low pressures. Pressures that are too high produce fogging and irregular turning. Fogging produces too many small droplets that fall too close to the sprinkler. Pressures that are too low cause improper jet breakup, producing a doughnut-shaped spray pattern. Under either condition, water is not uniformly distributed.

Operating pressures should be within the range specified by the irrigation system designer. Pressure gauges should be permanently installed at the irrigation pump and at entrances to zones. Test gauges periodically to verify that pressures are being measured accurately. This can be done by substituting a test gauge for the field gauges. Replace the field gauges if they are no longer accurate.

Pressures within zones can be measured at the sprinkler nozzles using pitot tube pressure gauges. Position pitot tubes in the discharge stream about 1/8-inch from the nozzle. Adjust the pitot tube by moving it slowly within the stream until the highest constant pressure reading is obtained.

Pressures recorded at critical points within the system, including at the pump discharge, at the entrance to zones, at the distant end of laterals, and at extreme high and low elevations, should be near the pressures specified by the system designer. Extreme deviations from the design pressures should be corrected before proceeding with further system tests.

As examples, low pump discharge pressure may occur because of pump wear, insufficient pump operating speed, insufficient water supply, a broken pipe downstream, too many open valves downstream, or eroded sprinkler nozzles that discharge excessive flow rates. Conversely, high pump pressures may indicate excessive pump speed, valves that are closed or partially closed downstream, or components that are clogged. Pump discharge rate measurements and visual inspections will help to determine which problem may have occurred. Similar flow rate measurements and visual inspections should be used to determine causes of excessively low or high pressures at other points in the system.

Measuring Sprinkler Application Rates

Sprinkler application rates must be known so that irrigation durations needed to apply specific depths of water can accurately be determined. Measure application rates under field conditions (1) to verify irrigation system designs and (2) to determine whether changes in application rates have occurred with time. Measurements to verify irrigation system design should be made soon after installation. Subsequent measurements should be made at least annually to track changes in system performance and to schedule repairs.

Three techniques can be used to measure application rates:

1. Measure the flow rate and area of each irrigated zone. Measure the flow rate with either a flow meter at the pump or at each zone. Units are normally gallons per minute (gpm). To convert to acre-inches per hour, divide the measured flow rate by 453. The average application rate per zone can then be calculated from:

Rate = Q / Area

(1)

where Rate = application rate in inches per hour (iph),

Q = total flow rate per zone in acre-inches per hour, and

Area = total irrigated zone area in acres.

For example, if the measured flow rate to a 10-acre zone is 906 gpm, this is equivalent to 906/453 = 2.0 acre-inches per hour. Then, the average application rate is 2.0 acre-inches per hour / 10 acres = 0.20 iph.

2. Measure the average flow rate and area covered by each sprinkler. For regularly spaced sprinklers, the application rate is then calculated from:

Rate = 96.3 q / [(Sl) (Sm)]

(2)

where Rate = application rate in inches per hour (iph),

q = sprinkler discharge rate in gallons per minute (gpm),

Sl = sprinkler spacing along the lateral in feet (ft), and

Sm = sprinkler spacing along the manifold between laterals in ft

As examples of the use of Equation (2), if 5-gpm sprinklers are spaced on a 40 ft x 40 ft square pattern, the application rate would be 0.30 iph. If 6-gpm sprinklers were spaced on a 40 ft x 60 ft rectangular pattern, the application rate would be 0.24 iph. If 4-gpm sprinklers are spaced on a 30 ft x 30 ft triangular pattern, the application rate would be 0.43 iph.

Sprinkler flow rate can be determined by either (a) measuring the volume discharged from typical sprinklers per unit time, or (b) measuring the sprinkler operating pressure with a pitot tube and using the manufacturer's specifications to determine the flow rate. Measuring the volume discharged is preferred because nozzle wear can increase the flow rate over manufacturer's specifications.

Sprinkler discharge can be diverted to a graduated cylinder or other volumetric container by slipping a flexible tube over the sprinkler nozzle. The tube should be large with respect to the nozzle diameter to avoid restricting the flow. Flow should only be measured while the sprinkler is operating at its design pressure. A stopwatch can be used to measure the sprinkler discharge collection time.

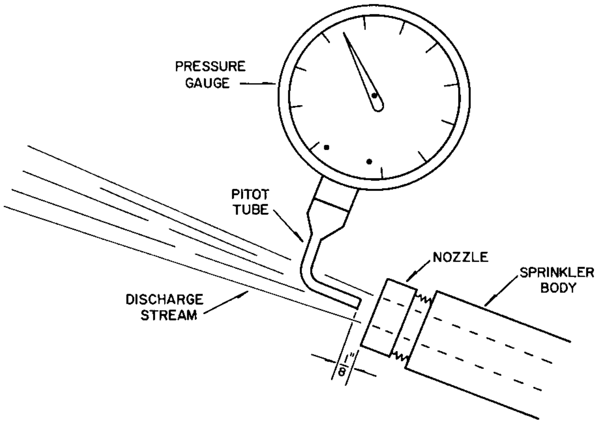

Figure 1. Using a pitot tube measure pressure at a sprinkler nozzle.

The pressure at the sprinkler nozzle can be measured by holding a pitot tube connected to an accurate pressure gauge in the discharge stream of the nozzle as shown in Figure 1. The nozzle size should be checked for wear or distortion with a feeler gauge such as a drill bit having the diameter specified for the nozzle. If the nozzle is worn or misshapen, it should be replaced with a new one. The sprinkler flow rate can then be determined by consulting the sprinkler manufacturer's specifications for the measured operating pressure and nozzle size. If the sprinklers have more than one nozzle, the total sprinkler flow rate can be determined by adding the flow rates of the individual nozzles.

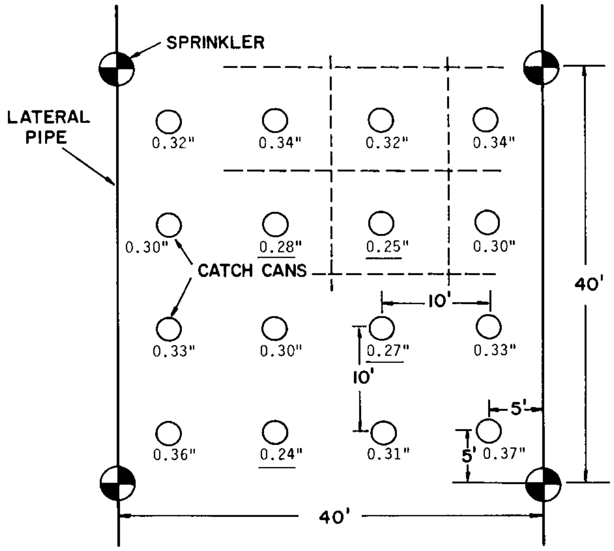

Figure 2. Typical layout of catch cans for uniformity.

To accurately determine the average sprinkler flow rate in an irrigated zone, measure several sprinklers (approximately 12 to 18). Some of the sprinklers measured should be near the inlet ends of the laterals, some near the center, and some at the distant ends. If the measured values are highly variable (more than ±15% from the average), the number of sprinklers tested should be increase.

If different sizes of sprinklers or nozzles are used in a zone, such as part-circle sprinklers at field boundaries, flow rates must be determined separately for each size. The total zone flow rate can then be determined by adding the average flow rates for the total number of sprinklers of each size in the zone. Finally, Equation (1) can be used to calculate the average application rate for the zone.

3. Measure the application rate directly with catch cans or rain gauges. The average application rate is then the average depth of water measured divided by the time during which the data were collected.

Because water is never applied with perfect uniformity under a sprinkler irrigation system, several catch cans must be placed between adjacent sprinklers. Normally at least 16 to 24 cans should be used. To simplify later uniformity calculations, use a number of cans that is a multiple of 4. Also, these tests should be conducted under the same conditions as those during typical applications. Avoid making tests during high wind conditions because wind distorts sprinkler patterns.

Figure 2 shows a typical layout of catch cans for uniformity measurements between the four sprinklers shown. The 16 cans are evenly spaced between sprinklers so that each is centered within and represents equal land areas. The numbers shown adjacent to the catch cans in Figure 2 are example catch can data which are used in later example problems.

Catch cans should all be of the same size and type, and should be placed upright so that their tops are level. Cans should be located on or near the soil surface, but above any vegetation which might obstruct access to the cans. For annual crops, schedule catch can tests when plants are small so that they do not interfere with the tests.

For large perennial plants such as citrus or other tree crops, catch can tests may be very difficult to conduct because of the need to elevate the cans above the canopies. Tests with cans under tree canopies are not appropriate because the canopies will distort the water distribution. If large unobstructed areas are available between trees, these areas may be used to estimate uniformities. This might be the case with young citrus trees. However, as trees grow, the tall canopies will distort water distributions, and the catch cans will need to be elevated to avoid the canopies.

In some citrus groves, sprinklers are located at about the same height or just above the tree canopy. In these cases, catch can tests may not be appropriate because the cans cannot be elevated sufficiently to clear the canopies and still be positioned sufficiently below the sprinklers to accurately measure water applications. To avoid evaporation losses during data collection, place a few drops of lightweight oil in the cans. The oil will disperse over the water surface and restrict evaporation. This is especially important for tests that require several hours to conduct.

In Figure 2, the depth of water collected in each can is given in inches. The average of the 16 depths is 0.31 inches. If the test was conducted for a 1-hr period of operation, then the application rate was 0.31 iph.

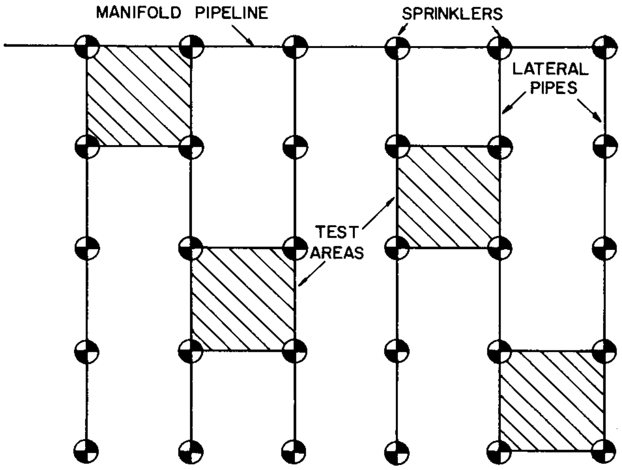

Figure 3. Example distribution of locations of catch can tests in a large irrigated field.

Because application rates may vary throughout a large irrigated field, measurements should be made at several locations as shown in Figure 3. Test locations should be selected over the entire range of pressures that might be encountered in the irrigation system. That is, locations should be selected both near and distant from the irrigation pump. Locations should also be selected at points of both high and low elevation.

Measuring Uniformity of Water Application

Uniformity of water application is a measure of the variability in depths of water applied at different points throughout an irrigated zone. Uniformity of water application can be measured using catch cans set on or near the soil surface. Follow the procedures previously described in this bulletin for application rate measurements.

Uniformities are normally measured under no-wind conditions. Under no-wind conditions, the maximum possible uniformity is measured for the existing system hydraulic characteristics and sprinkler selection.

Uniformity will be lower when sprinkler systems are operated during windy conditions. However, that uniformity may be more representative of the long-term average uniformity if the sprinklers are normally operated under windy conditions. Where prevailing winds are consistently strong, such as along the coasts in Florida, sprinklers must be spaced closer together than under no-wind conditions. For no-wind conditions, sprinklers are typically spaced at 55% to 60% of their diameters of coverage. This should be reduced to 50% for low wind speeds (less than 5 mph) and to 30% for wind speeds above 10 mph.

Uniformity of water application with sprinkler irrigation systems is usually reported as either the distribution uniformity (DU) or Christiansen's Uniformity Coefficient (UC)

Distribution Uniformity

DU is calculated as the ratio of the depth measured in the low quarter of the irrigated area to the overall average depth applied.

DU = 100% (Average Low Quarter Depth of Application / Overall Average Depth of Application)

(3)

where DU is expressed as a percent. The average low quarter depth is determined by inspecting the data collected and calculating the average of the smallest 1/4 of the measured depths. The overall average is the arithmetic average of all of the catch can data. The computations are simplified if the total number of data are a multiple of 4.

DU can be calculated using the data shown in Figure 2. The low quarter of the 16 data points are the four values: 0.24, 0.25, 0.27, and 0.28 inches, shown underlined in Figure 2. The average of these four low quarter values is 0.26 inches. The overall average of all 16 points is 0.31 inches. Then, from Equation (3):

DU = 100% (0.26 inches) / 0.31 inches = 83.9%

Christiansen's Uniformity Coefficient

Christiansen's Uniformity Coefficient (UC) is another widely-used method of calculating the uniformity of water application from sprinkler irrigation systems:

UC = 100% [1 - (Average Deviation from the Average Depth of Application / Overall Average Depth of Application)]

(4)

where UC is expressed as a percent. The average deviation from the average depth of application is calculated by averaging the absolute values of the differences between each of the individual depths and the average depth, and the overall average depth of application is defined as before.

For the data given in Figure 2, the overall average depth measured was 0.31 inches. In Figure 2, the absolute values of the differences between each of the individual depths and the average depth is shown in parenthesis below each of the depths measured. The sum of the absolute values of these differences for each of the 16 data points is 0.46 inches. The average deviation is then 0.46/16 = 0.029 inches, and

UC = 100% [1.0-(0.029/0.31)] = 92.7%

Acceptable Uniformity Coefficients

Acceptable values of uniformity coefficients vary with the type of crop being grown and the specific uniformity equation used. Both equations result in approximately the same values when uniformity is high. However, DU values are normally much lower than UC values when uniformities are low.

For high cash value crops, especially shallow rooted crops, the uniformities should be high (DU values greater than 80% or UC values greater than 87%). For typical field crops, DU values should be greater than 70% (UC values greater than 81%). For deep rooted orchard and forage crops, uniformities may be fairly low if chemicals are not injected (DU values above 55% and UC values above 72%).

Uniformity coefficients should be high (DU values greater than 80% or UC values greater than 87%) whenever fertilizers or other chemicals are injected into the irrigation systems. If uniformity coefficients are lower than these values, system repair, adjustment or modification may be required. If uniformity coefficients are periodically measured (at least annually), system repairs or adjustments can be scheduled when coefficients fall below the above values.

Runoff

Runoff will reduce the amount of water applied to high areas and may increase the amount applied in low areas where the water may collect and infiltrate. During system tests and during normal sprinkler operation, runoff should not occur. This is normally not a problem on typical Florida sandy soils, but if runoff occurs, design or management changes should be made to eliminate it. Shorter, more frequent irrigations may be scheduled to reduce runoff, or it may be necessary to reduce nozzle sizes to reduce application rates. If the system operation must result in runoff (such as in some strawberry and nursery operations), recovery ponds can be used to collect runoff for future use.

Summary

This publication described techniques which can be used to evaluate sprinkler irrigation systems under field conditions. Techniques were presented (1) to measure operating pressures, (2) to measure application rates, (3) to measure the uniformity of water application, and (4) to avoid runoff under field conditions for existing solid or portable set sprinkler irrigation systems. Critical values of uniformity coefficients for various crops and production systems were presented.

Reference

Merriam, J.L and J. Keller. 1978. *Farm Irrigation System Evaluation: A Guide for Management.* Utah State University. Logan, Utah. 271 pages.