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## Field Procedures and Data Analysis for the Cornell Sprinkle Infiltrometer



For questions and purchase inquiries, contact:

Harold van Es, Professor: (607) 255-5629, [hmv1@cornell.edu](mailto:hmv1@cornell.edu), or

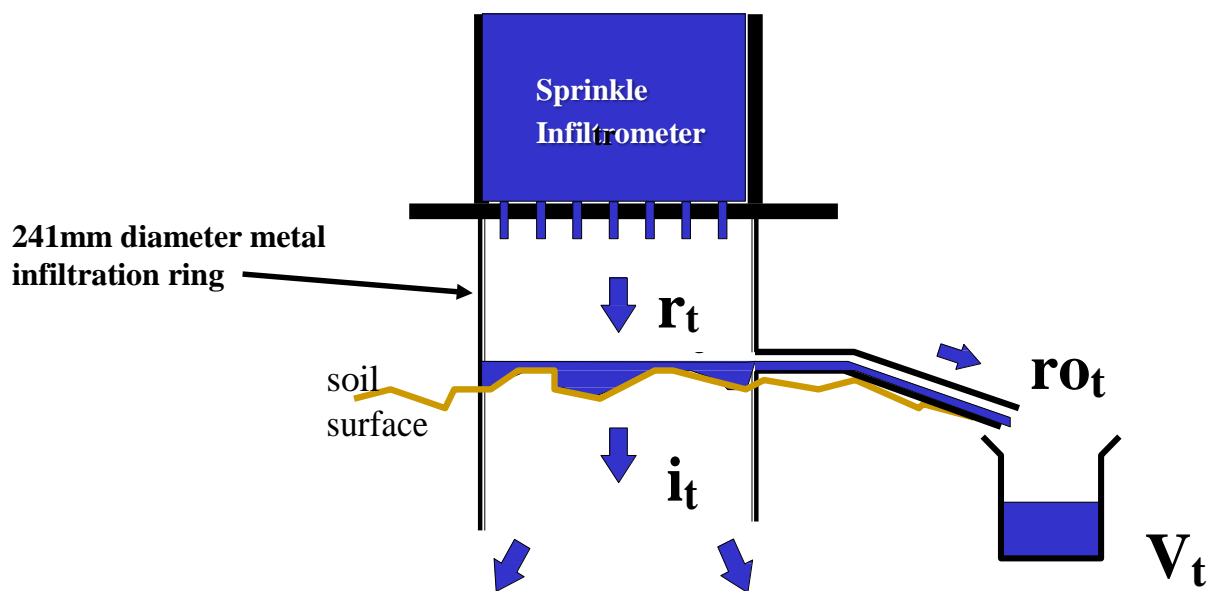
Robert Schindelbeck, Extension Associate: (607) 227-6055

Department of Crop and Soil Science, Cornell University, Ithaca, NY 14853-1901

## The Cornell Sprinkle Infiltrometer

Soil infiltrability is an important soil quality indicator, as it has important agricultural and environmental implications and is strongly affected by land management practices. Measurement of soil infiltrability is generally done through ponded ring infiltration or simulated rainfall, each having specific advantages and disadvantages. The Cornell Sprinkle Infiltrometer (Ogden et al., 1997) was designed to combine the advantages of both. It also allows for easy and rapid measurement of soil infiltration, as this is essential to adequately estimate spatially and temporally-variable infiltration behavior (van Es, 1993).

The Cornell Sprinkle Infiltrometer system consists of a portable rainfall simulator that is placed onto a single 241-mm (9 1/2") inner diameter infiltration ring (Fig. 1) and allows for application of simulated rainfall at a wide range of predetermined rates. The apparatus permits the determination of several important soil hydrological properties: Time-to-runoff, sorptivity, and field-saturated infiltrability.



**Fig. 1. Infiltrometer schematic**



**Fig. 2.** Field infiltrability kit. These items fit nicely into a 5 gallon pail with a 2 pound hammer and a 4" x 4" x 12" wooden block

In contrast to most other ponded infiltration measurements, this approach:

- Wets the soil in a more natural manner and eliminates soil slaking as a result of instantaneous ponding
- Reduces unnaturally high contributions of macropore flow under ponded conditions
- Provides a realistic surface boundary condition, including the effects of soil surface roughness which can greatly influence infiltration behavior
- Is conservative with water

Compared to most other rainfall simulators, the Cornell Sprinkle Infiltrometer measures infiltrability for a relatively small soil surface area. However, its main advantages are:

- Low cost
- High portability
- Allows for rapid measurements by a single person
- Easy calibration for a wide range of simulated rainfall rates
- Conservative water use

The Cornell Sprinkle Infiltrometer employs a single, rather than a double infiltration ring, and makes adjustments for three-dimensional flow at the bottom of the ring based on research by Reynolds and Elrick (1990).

## **Field Procedures**

### ***Sprinkler Preparation***

Although the sprinklers are robustly built for use under field conditions, the user should be aware that the capillary tubes at the bottom of the unit are the most sensitive part of the equipment. Efforts should be made to minimize contact of the tubes with soil or debris. Use of water with high sediment content should be avoided as it may increase the potential for clogging of the capillaries. Since natural rainfall is low in soluble salts, it is recommended (but not always logistically feasible) to use water of low ionic strength. This may be especially critical for sodic and other soils that are subject to slaking.

Fill the sprinkler when positioned on a stable flat surface. Remove the large rubber stopper and air-entry tube, and pour water into the vessel. Then re-insert the large stopper and air-entry tube assembly tube firmly to insure that the stopper seal is air-tight. (This is important as air should only enter the vessel through the air-entry tube.) The interface between the small stopper and the air-entry tube should also be air-tight. Some vacuum grease may be used to insure this, while still allowing for easy adjustment of the tube.

Once the sprinkler vessel has been filled and the stoppers firmly reinstalled, open the pinch clamp and blow gently into the air-entry tube for a few seconds to apply additional air pressure into the device. As your lungs empty, quickly release the accumulated air pressure by lifting on the large stopper. This application of air pressure fills all of the capillary tubes with water and purges them of air. This should be repeated any time the unit has water added to it. Close the pinch clamp on the air-entry tube and the dripper will soon develop a vacuum in the air space above the water and the capillaries will cease dripping after a few seconds. The sprinkler is now on stand-by and ready for use without losing any water in the meantime.



**Fig. 3.** The air-entry tube slides up or down (within the green stopper at right) to control the drip rate of the Cornell Sprinkle Infiltrometer

### ***Sprinkler calibration***

The sprinklers are designed to apply water at a wide range of simulated rainfall rates. The rate can be changed by sliding the air-entry tube up (for higher rates) or down (for lower rates). It is recommended to calibrate the sprinkler for a rainfall rate of 20 to 30 cm/hr. This generally insures that ponding will occur for every measurement, and still allows for a measurement period of one hour without requiring refills.

**Note:** Alternatively, the sprinklers may be calibrated for an event of known recurrence period for the region of the study (e.g., a 50-year, 1 hour event). This will generally not insure ponding for all measurements, in which case one might interpret the measurement location as having "sufficiently high" infiltrability. This may create challenges when trying to analyze the data statistically, as it will not provide quantitative data for those sites.

The actual sprinkling rate in the field may vary slightly from the calibrated rate as a result of temperature variations in the water. This is not a problem, as the actual application rate is directly measured in the procedure.

To calibrate the sprinkler, perform the following:

1. Set the air-entry tube to the desired level. The 30 cm/hr or 0.5 cm/min sprinkle rate is generally achieved when the bottom of the air-entry tube is located at 10 cm above the bottom of the container. This is therefore a good starting point for the calibration effort.
2. Measure the height of water level in the sprinkler vessel (**H1**). It is easiest to measure and record it in cm with one decimal value (e.g. 41.2 cm).
3. Open the pinch clamp on the air-entry tube, while simultaneously starting a stopwatch
4. Allow for 3 minutes of sprinkling and read the water level exactly at this time (**H2**)
5. Calculate the rainfall rate (cm/min) as

$$\mathbf{[H1-H2]/3}$$

6. Allow the dripper to continue to drip at this air-entry tube level for 2 more intervals to ensure accurate data collection.
7. If the actual rainfall rate is below the desired rate, move the air-entry tube upwards. Move it down if it is above the desired rate.
8. Repeat the procedure until the desired rate is achieved. Note that the calibrated rainfall rate does not need to be very exact, as the actual rate is determined for each field measurement, and variations are accounted for in the data analysis.

Once the sprinkler has been calibrated for the desired rate, refill the vessel and reinstall all stoppers. It is now ready for actual field measurements. Note that calibration generally does not have to be repeated. It can also easily be checked with each subsequent field measurement.

### ***Ring Insertion***

The infiltration ring should be inserted without causing significant disturbance to the soil. This is best performed with the use of a hydraulic device that pushes the ring into the soil with a steady and constant force. Pounding rings into the soil using a hammer tends to cause some soil disturbance, especially in dense soils, and is therefore less preferred. In all cases, it is recommended to lay a wooden 4" by 4" of about 30 cm length horizontally on top of the ring and applying the driving force to it. Before inserting the ring, carefully remove pieces of debris, crop residue and small rocks that are immediately below the edge of the ring, as they would cause soil disturbance when the ring is pushed in. In rocky soils, multiple attempts may be required to insure that ring insertion occurred without excessive disturbance.

The ring should be inserted to a depth where the lower edge of the round overflow hole is flush with the soil surface. This corresponds to an insertion depth of 7.5cm. The ring should always be inserted with the 2.5cm runoff hole in the downhill direction of the surface microrelief within the ring. Note that on rough soils the infiltration measurement will account for any effect of surface storage capacity, which can greatly affect infiltrability.

Once the ring has been installed, insert the runoff tube assembly (stopper and tubing) into the ring (**Fig. 1 and 2**). At the end of the tube, dig a small hole about 20cm by 20cm by 20cm to place the beaker. The hole for the beaker should be sufficiently distant (30 cm or more) from the infiltration ring to not interfere with water flow patterns. The runoff tubing should slope away from the ring to insure that overflowing water does not back up and readily empties into the beaker. The beaker itself should therefore also be positioned sufficiently low in the excavated hole.

The sprinkler may now be placed on top of the ring in preparation for the measurements (as in **Fig. 1**). Alternatively, the sprinklers may be suspended above the ring (e.g., off a tripod). This will allow the simulated raindrops to gain velocity and more closely reproduce the energy of natural rains.

### ***Measurements***

The following steps outline the measurement procedure:

1. Measure the height of the water level in the sprinkler vessel (**H<sub>1</sub>**)
2. Open the pinch clamp on the air-entry tube while simultaneously starting a stopwatch. Monitor the outflow tube to determine whether water is being discharged into the beaker. During this period, it is advised to slightly rotate the sprinkler every minute or so (more often when the sprinkler is suspended) to prevent raindrops impacting the soil surface in the same location.
4. When water starts flowing out of the tube, record the time (**T<sub>RO</sub>**, time to runoff in minutes). The runoff water should now be flowing into the beaker.
5. After three (or so) minutes, pour the water from the beaker into the graduated cylinder. This should be done while not spilling water that continues to come from the outflow tube (e.g., by quickly replacing the full beaker with another empty one, or temporarily blocking the outflow tube).
6. Measure the runoff volume (**V<sub>t</sub>**) in the graduated cylinder (in ml). Record both **V<sub>t</sub>** and the time at which water was collected.

7. Repeat steps 5 and 6 for as long as desired (generally up to one hour), or until the water level in the vessel has reached the bottom of the air-entry tube. Do not continue beyond this point as the sprinkle rate will gradually decrease. In most cases, steady-state water intake conditions will have occurred within an hour. It may take longer with extremely dry soils and those that have shrinkage cracks that close very gradually during extended wetting.

8. At the end of the measurement period, determine the water level in the vessel (**H2**) and the time at which it is taken (**T<sub>f</sub>**).

### ***Field Infiltrability Data Sheet***

A useful field data sheet is provided in Appendix 1 of this User Manual.

## **Data Analysis**

The simulated rainfall rate (**r**, constant throughout the experiment) is determined by

$$\mathbf{r} = [\mathbf{H1} - \mathbf{H2}] / \mathbf{T_f}$$

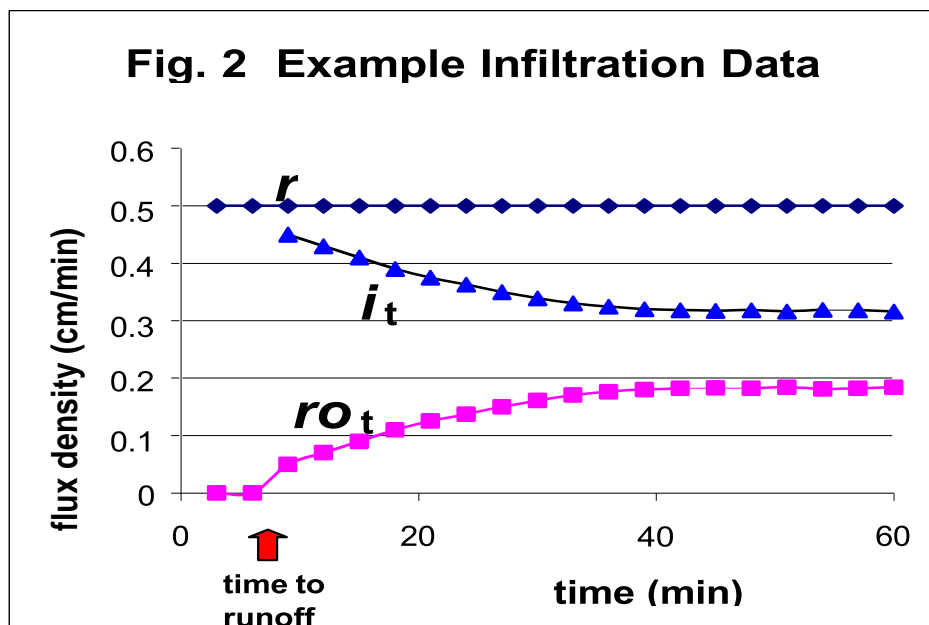
The runoff rates (**ro<sub>t</sub>**, cm/min) are determined by

$$\mathbf{ro_t} = \mathbf{V_t} / (457.30 * \mathbf{t})$$

where 457.30 is the area of the ring, and **t** is the time interval for which runoff water was collected (3 minutes in our case). Infiltration rates (**i<sub>t</sub>**) are determined by the difference between the rainfall rate and runoff rate:

$$\mathbf{i_t} = \mathbf{r} - \mathbf{ro_t}$$

**Figure 4.** Rainfall, runoff and infiltration rates for a typical measurement



### *Estimation of Sorptivity*

Time-to-runoff (**T<sub>RO</sub>**) is an important soil hydrological parameter that is dependent on the rainfall rate (**r**) as well as the initial soil water conditions. Runoff will occur earlier if **r** is higher and the soil is wetter. Sorptivity (**S**) is a more universal soil hydraulic property that describes early infiltration independent of rainfall rate. It is estimated by (Kutilek, 1980):

$$S = (2T_{RO})^{0.5} * r$$

Sorptivity also accounts for variable sprinkle rates which are difficult to avoid under field conditions, and provides an integrated assessment of early infiltration, including the effect of surface water storage with rough soil surfaces.

### *Estimation of Field-Saturated Infiltrability*

Field-saturated infiltrability (**i<sub>fs</sub>**) reflects the steady-state infiltration capacity of the soil, after wet-up. It should be based on the data collected at the end of the measurement period, or whenever steady-state conditions occur. Since the apparatus has a single ring, the measured infiltration rate needs to be adjusted for three-dimensional flow at the bottom of the ring. The required adjustment is generally greater when the ring insertion depth is shallower and the soil type is finer-textured. The adjustment factors suggested below are based on Reynolds and Elrick (1990) who used numerical modeling to estimate the effects of three-dimensional flow at the bottom of the ring.

For the 7.5 cm ring insertion depth, multiply the measured infiltration rate by the constant listed in Table 1 to obtain the field-saturated infiltrability:

For example, for a ring insertion depth of 7.5 cm on a loam soil, the field-saturated infiltration rate is estimated as

$$i_{fs} = i_t * 0.80$$

**Table 1.** Conversion factors for field-saturated infiltrability to account for three-dimensional flow at the bottom of the ring (based on Reynolds and Elrick, 1990)

<u>Soil Type</u>	<u>Ring Insertion Depth</u>	
	<u>7.5 cm</u>	<u>15 cm</u>
sands and gravels	0.95	0.99
loams	0.80	0.94
clays and heavy clay loams	0.60	0.88



## Using the Cornell Sprinkler to Observe and Measure Wet Aggregate Stability

### *Background*

There is a long-standing interest in the stability of soil crumbs to wetting. The context of this interest includes crop yields (De Boodt et al., 1961), soil erosion potential (Yoder, 1936; Bartes and Roose, 2002), soil surface crusting (Le Bissonnais et al., 1989) and especially soil quality or soil health (Moebius et al., 2007; Andrews and Carroll, 2001). Soils are typically dried, sieved to appropriate sizes and submerged into a water bath. Alternately, some researchers have used sprayers to deliver water drops with rainfall-like drop distribution.

### *Teaching/ demonstration*

Soils that are loose and crumbly (friable) when damp are most hospitable to plant growth. For example, if a fairly dry, baseball-sized soil clod is dropped from waist height, a soil with good structure or aggregation will break nicely into mellow aggregates or 'crumbs'. A degraded soil remains massive and difficult to break apart. In the tests described here we support the sprinkler above a test sieve containing soil crumbs and apply a vigorous simulated "storm" of water droplets to the crumbs. Crumbs that lose their integrity and 'melt' are rinsed through the sieve into a filter paper and are measured as unstable and contributing to the undesirable soil conditions of surface sealing and crusting, hardsetting (clodding), and slaking. The Cornell Sprinkle Infiltrometer and the Wet Aggregate Stability kit can be used to test the stability of these aggregates to simulated rainfall. Field demonstrations of the theory of aggregate stability to breakdown can be easily created using soil crumbs harvested from target areas in the field.

**Figure 5.** On the left are the 2mm and 0.25mm sieves in the wet aggregate stability kit. Test crumbs are collected (crumbs < 2mm and > 0.25mm) and placed on the 0.25mm sieve nested in the filter paper, nested in the orange funnel and atop the ring stand. On the right is a dripper suspended from a tripod above some target soil crumbs in a field day demonstration.



### ***Research applications***

The uniform droplet size created by the capillary tubing allows the rainfall simulator to be used for measurement of soil aggregate stability under predetermined rainfall energy levels (Moebius et al., 2007). The Wet Aggregate

Stability percentage of a soil sample is used as an indicator of soil structural stability in the Cornell Soil Health Assessment (Gugino et al., 2007). In this assessment, the wet aggregate stability of soil health samples is determined using air dried soil on the aggregate size fraction 0.25mm-2mm. From the total weight of dry aggregates tested, the weight of slaked soil and the weight of stones retained on wetted sieve are measured and the difference determines the percent of stable soil as aggregates.

$$\text{Percent stable soil} = 1 - \left( \frac{\text{Failed soil (g)}}{\text{Total soil Tested (g)} - \text{Stones and debris (g)}} \right)$$

**Figure 6.** Extra large (60cm diameter) Cornell Sprinkle Infiltrometer drips on four 20cm sieves with soil samples simultaneously in the Cornell Soil Health Lab



In this lab procedure, each soil sample is placed on a 20cm diameter soil sieve which receives 1.25cm water depth (as drops) in 5 minutes. In this time about 11,700 drops of 4mm diameter with a total weight of 0.393kg are delivered to the soil on the sieve. These drops reach a velocity of 3.1m/s as they fall the 50cm distance (terminal velocity for this sized drop is 8.8m/s). The total Kinetic Energy (KE) delivered in 5 minutes is:

$$KE = \frac{1}{2} m * v^2$$

$$KE = \frac{1}{2} (0.393\text{kg})(3.1\text{m/s})^2$$

$$KE = 1.9 \text{ Joules/ 5 minutes}$$

Suspending the dripper at *different heights* changes the terminal velocity of the droplets. See **Table 2** for the effects of changing the dripper height on energy delivered to the target. *Increasing the drip rate* at each height would have a linear effect on the amount of energy delivered per minute, as this would affect the mass of water delivered per unit time.

**Table 2.** Effect of dripper height on fall velocity of individual drops (taken from Epema and Riezebos, 1984) and total energy delivery to the soil sample on the sieve in five minutes

Dripper head pressure (cm)	Drip rate (mm/min)	Average drop diameter (mm)	Drop fall height (m)	Drop fall velocity (m/s)	Total kinetic energy delivered (Joules / 5 minutes)
4	2.5	3.96	0.5	2.96	1.9
4	2.5	3.96	1	4.06	3.2
4	2.5	3.96	1.5	5.00	4.9
4	2.5	3.96	2	5.65	6.3
4	2.5	3.96	10	8.41	13.9
4	2.5	3.96	$\infty$	8.75	15

## Other Uses

The Cornell Sprinkle Infiltrometer can be employed for other measurements of soil physical behavior. In a manner similar to the infiltration measurements, the sprinkler system may be employed to measure soil hydraulic conductivity in the field with rings inserted in different soil horizons in-situ. This can also be done in the laboratory using soil cores, in which case no correction for three-dimensional flow would be required.

The sprinkle system may also be employed when natural soil wetting is required in the laboratory or field.

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