INFILTRATION

A Practical Guide for Comparing Crop Management Practices

CIMMYT

The International Maize and Wheat Improvement Center, known by its Spanish acronym, CIMMYT® (www.cimmyt.org), is a not-for-profit research and training organization with partners in over 100 countries. The center works to sustainably increase the productivity of maize and wheat systems and thus ensure global food security and reduce poverty. The center's outputs and services include improved maize and wheat varieties and cropping systems, the conservation of maize and wheat genetic resources, and capacity building. CIMMYT belongs to and is funded by the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org) and also receives support from national governments, foundations, development banks, and other public and private agencies. CIMMYT is particularly grateful for the generous, unrestricted funding that has kept the center strong and effective over many years.

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Acknowledgements

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Infiltration

1. Introduction

Infiltration rate is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface will take one hour to fully infiltrate (Brouwer et al., 1988). Infiltration is a complex process that depends upon the physical and hydraulic properties of the soil, soil water content, previous wetting history, structural changes in the soil layers, and air entrapment (Walker, 1989). Various soil characteristics can influence the infiltration rate, including soil texture and structure, cracking, cultivation practices, and soil swelling (Chen-Wuing et al., 2003). In dry soil, water infiltrates rapidly. This is referred to as the initial infiltration rate. As more water replaces air in the pores, the water from the soil surface infiltrates at a slower rate and eventually reaches a steady rate when the soil is saturated with water. This is called the basic infiltration rate (Brouwer et al., 1988). Knowledge of the basic infiltration rate is important for the construction of an effective irrigation system. When the amount of irrigation water exceeds the infiltration rate, run-off can occur, causing an unequal water distribution and possibly leading to erosion.

Infiltration curves and basic infiltration can be measured with a double ring infiltrometer. Measuring infiltration with this device is a time consuming and invasive measurement, so a simpler protocol has also been included below. Small ring infiltration is an alternative approach which is faster and doesn't disrupt the field to the same extent as the double ring infiltrometer, but it is less accurate as it does not compensate for lateral flow. An advantage of using small ring infiltration is that it can be used to compare between plots multiple times during the growing season. Furthermore, taking measurements with a double ring infiltrometer will always saturate the soil, while small ring infiltration measurements can be achieved with a variable amount of water. Using a small amount of water will give an indication of what happens during rainfall events, while using larger amounts will yield a value more similar to the basic infiltration rate. Bouwer (1986) found that infiltration rates based on cylinder infiltrometer measures are fraught with errors and uncertainties. Measurement errors can occur due to soil disturbance by the insertion of the cylinder into the soil. In soils with a surface crust or other restricting layers at or near the surface, infiltrometers can disrupt such restricting layers resulting in drastic increases in infiltration rates. Also, clays and other fine particles, temporarily brought into suspension in the water inside the cylinder, can settle out on the soil during the measurement, creating a restricting layer on the surface.

The time-to-pond methodology was proposed by Govaerts et al., (2006) to overcome these errors and provide a fast, reliable, and simple (thus, potentially useful for on-farm research) measure of direct surface infiltration. In this methodology, a piece of metal wire is placed over the soil to avoid soil structure disruption. Since water flow out of the area is not impeded by the wire, this methodology also provides an indirect measure of runoff (not considered in cylinder infiltrometer measures). Direct runoff measures are often time and labor intensive (Barthes and Roose, 2002; Hellin, 2006). Runoff is directly related to soil erosion which depends on surface physical soil quality (i.e., topsoil aggregate stability) (Barthes and Roose, 2002) and management (i.e., presence of crop residue cover avoiding direct raindrop impact into the soil) (Neave and Rayburg, 2007). Time-to-pond provides a measure of infiltration versus runoff in which both aspects, physical soil quality and management, are accounted for. Thus, measurements not only provide a basis for infiltration comparisons between soils but also information on management practices related to reduced runoff incidence. Methodologies have often ruled out management factors. For instance, Anderson and Ingram (1993) recommended removing surface litter previous to infiltration measures. This ignores the fact that crop residue management strongly modifies water infiltration rates into the soil (Hellin, 2006).

Given the variability of physical soil quality, especially in the topsoil, and variable residue levels at the surface due to decomposition and management, multiple spatial and temporal measures of time-to-pond are highly recommended. Time-to-pond measurements are quick and non-disruptive but the main limitation is that they are not quantitative. Time-to-pond values can only be used to make comparisons between plots in a single trial. As it is a fast and easy measurement it can also be used in the field to show farmers the difference in infiltration between fields.

Each of the summarized methods has advantages and disadvantages (Table 1). The method to use needs to be determined for each study depending on research objectives, available resources and production system.

2. Double Ring Infiltrometer

2.1. Materials and Equipment

- Approximately 200 l water per measurement (depending on soil; less water is needed when a ring of metal sheets is used instead of an earth bund)
- Buckets
- 2 cylinders with a diameter of 15 cm
- Spade
- Equipment for excavation when performing a measurement at depth
- Metal sheets of approximately 60 × 30 cm (only when available and for surface measurements)
- Small water container (approx. 500 ml)
- Plastic bags
- Hammer
- Piece of wood
- 2 measuring rods
- Hessian or jute cloth
- Stopwatch
- 2 or 3 people
- Datasheet and pencil

2.2. Procedure

Two rings are hammered 10 cm into the soil ensuring a distance of 15 cm between each of the rings. During hammering, a piece of wood can be placed on top of the rings to protect them from damage and it is important to keep the side of the rings vertical during this time. The measuring rod is driven into the soil until it is firm (approximately 3–10 cm, depending on the hardness of the soil) and the zero level is recorded. An earth bund is then constructed around the two rings (keeping at least 10 cm from the border of each ring) to a height of 20 cm and hessian bag (or other suitable material) laid against the inside of the bund to protect the soil surface when pouring in the water. Using a bucket, the water is added to the space between the two rings and the bund to a height of approximately 10 cm. Placement of the water into this area of the bund is done to prevent a lateral spread of water from the infiltrometer. It is important to maintain the water in the rings and in the bund at the same level to prevent infiltration from inside the rings to outside the rings. Measurements can be taken at the surface (surrounded by an earth bund) or in a pit of a chosen depth (Figure 1). If metal sheets are available, they can be used as an alternative to the earth bunds for surface measurements.

The test is initiated by pouring water into each of the rings (using the small water container while protecting the soil with a plastic bag) until the height of the water is approximately 10 cm. This process should be completed quickly, and the time at which it begins along with the water level on the measuring rod recorded. When the water level has dropped approximately 1 cm, the time and the water level is recorded. The ring is then refilled to the original height of approximately 10 cm and the details again recoded to begin a new measurement.

Record at least one measurement every 30 minutes in a clay soil and one every 20 minutes in soils with a coarser texture. Continue the test until the drop in water level is constant over equal time intervals. The test can be

Table 1. Advantages and disadvantages of various infiltration measurement methods.

	Double ring infiltrometer	Small ring infiltrometer	Time-to-pond
Advantages	Accurate	Fast	Fast
	Compensates for lateral flow	Less Disruptive	Takes management factors (like residue cover) into account
	Quantitative	Quantitative	Not disruptive
Disadvantages	Disruptive	Does not compensate lateral flow	Not quantitative
	Time consuming	Less accurate	Short duration (only direct infiltration)

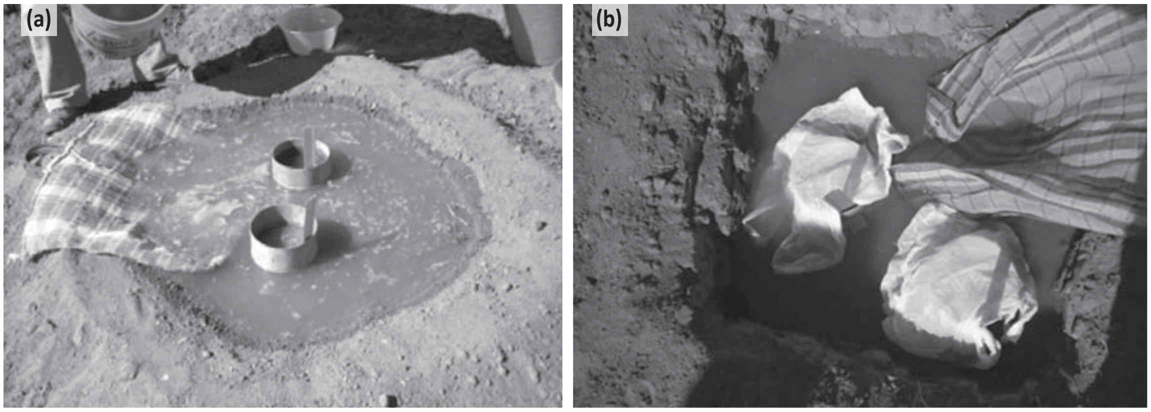

Figure 1. (a) Infiltration measurement at the soil surface with two rings of 15 cm surrounded by an earth bund (before covering the ring with plastic bags); (b) infiltration measurement at 40 cm depth in a pit of 60 × 60 cm (rings covered with plastic bags to prevent evaporation).

stopped when the same reading is obtained at least three consecutive times. Be careful to maintain the water level outside the ring similar to that inside during the entire measurement period. It is preferable that the rings are covered with plastic bags during the measurements to prevent evaporation.

2.3. Calculation

The basic infiltration rate k_s is calculated according to Reynolds and Elrick (1990) and Reynolds et al. (2002) (Figure 2):

$$\frac{q_s}{k_s} = \frac{H}{C_1 d + C_2 a} + \frac{1}{\alpha (C_1 d + C_2 a)} + 1$$

Where:

q_S = quasi-steady infiltration rate (measured) (mm h^{-1})
k_S = basic infiltration rate (mm h^{-1})
H = steady depth of ponded water in the ring (use the average of the initial and final water level) (cm)

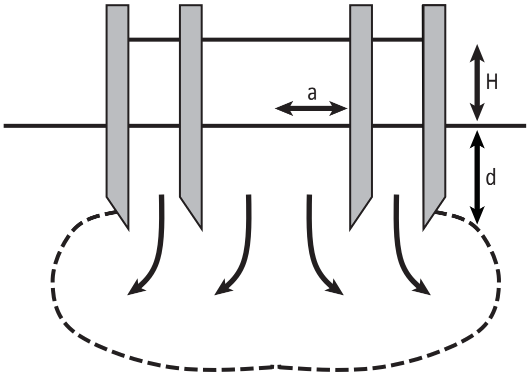

Figure 2. Schematic of equation variables.

C_1 = 0.316 π (empirical constant for $d \geq 3$ cm and $H \geq 5$ cm)
C_2 = 0.184 π (empirical constant for $d \geq 3$ cm and $H \geq 5$ cm)
d = depth of ring insertion into the soil (cm)
a = ring radius (cm)
α = effective macroscopic length (cm^{-1})

When the basic infiltration rate k_s is determined as equal to the quasi-steady infiltration rate q_s measured in the field, it is often overestimated, as q_s depends on H, d, a and α (Reynolds et al., 2002). Soil texture/structure categories for site estimation of α (Table 2) and a range of basic infiltration rates corresponding to different soil textures (Table 3) are outlined below.

Table 2. Soil texture/structure categories for site-estimation of α (adapted from Elrick et al. 1989).

Soil texture and structure category	α (cm^{-1})
Compacted, structureless, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments	0.01
Soils that are both fine textured (clayey or silty) and unstructured; may also include some fine sands	0.04
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils	0.12
Coarse and gravelly sands; may also include highly structured or aggregated soils, as well as soils with large and/or numerous cracks, macropores	0.36

Table 3. Range of the basic infiltration rate according to soil texture (Brouwer et al. 1988).

Soil type	Basic infiltration rate (mm h^{-1})
Sand	More than 30
Sandy loam	20–30
Loam	10–20
Clay loam	5–10
Clay	1–5

2.4 Worked Example

Infiltration was measured in a 1.10 m pit in a soil profile at Ciudad Obregon, Mexico. Soil texture at that depth was sandy clay loam. Using Table 4 it can be calculated that q_S = 9 mm/20 min = 27 mm/hour

$$\frac{q_s}{k_s} = \frac{H}{C_1 d + C_2 a} + \frac{1}{\alpha(C_1 d + C_2 a)} + 1$$

$$= \frac{9.55\text{ cm}}{0.316\pi \times 10\text{ cm} + 0.184\pi \times 7.5\text{ cm}} + \frac{1}{0.04\,(0.316\pi \times 10\text{ cm} + 0.184\pi \times 7.5\text{ cm})} + 1 = 3.42$$

$$k_s = \frac{27\text{ mm/h}}{3.42} = 7.89\text{ mm/h}$$

Table 4. Example of an infiltration measurement with a zero level of 4.5 cm in a structureless, sandy clay loam soil.

Time (h.min.s)	Water level reading (cm) Before filling	Water level reading (cm) After filling	Time difference (min)	Difference in water level (mm)
0.00.00		14.5		
0.05.39	13.5	14.5	5.39	10
0.26.34	13.5	14.5	21.05	10
0.44.58	13.5	14.5	18.24	10
1.04.35	13.7	14.5	19.37	8
1.24.54	13.6	14.5	20.19	9
1.45.00	13.6	14.5	20.05	9
2.05.00	13.6	14.5	20.00	9
2.25.00	13.6	14.5	20.00	9
2.45.00	13.6	14.5	20.00	9

3. Small Ring Infiltration

3.1 Materials and Equipment

- 15 cm diameter cylinders
- Water
- Buckets
- 250 ml beaker
- Stopwatch
- Datasheet and pencil

3.2 Procedure

It is necessary to measure infiltration immediately following or prior to soil moisture determination. The cylinder is placed over the soil surface and driven 1 cm into the soil (to avoid water runoff), ensuring residues and weeds are removed before inserting the cylinder.

Water (250 ml) is poured into the cylinder at time 0 and the stopwatch is started. The time taken for all of the water to infiltrate is recorded. Alternatively, add 10 to 15 consecutive volumes of 100 ml water to the soil and record the time required for each volume to infiltrate.

When taking measurements in a bed planting system, measurements can be recorded separately on top of the bed and in the furrow.

3.3 Worked Example

In this example 250 ml of water infiltrated in 89 seconds. Therefore the infiltration rate is:

$$= \frac{250\text{ ml}}{89\text{ s}} = 2.81\text{ ml/s}$$

4. Direct Surface Infiltration or Time-to-Pond

4.1 Materials and Equipment

- Watering can (smaller for measurements being taken in beds)
- Water (5 l per sample)
- Ruler (min. 30 cm)
- White adhesive tape
- Metal wire ring (53 cm diameterfor measurements with flat planting; 40 cm for measurements in beds)
- Stopwatch
- Datasheet and pencil

4.2 Procedure

Firstly, the watering can is calibrated so that exact values of poured water can be recorded. This can be achieved by pouring known volumes into the can and recording the water level on a ruler attached to the can (Figure 3).

For field measurements, place the wire ring over the soil (with the planting row located within the wire diameter) without impeding water to flow out of the area (role of the first person; Figure 4). A second person then indicates the initial water level within the watering can, while a third person records all data on a data sheet. The second person then pours water from a height of 75 cm into the center of the ring under a stable angle (Figure 5), and the third person initiates the stopwatch. When water flows out of the ring (as indicated by the first person), the second person stops the water flow and the stopwatch is also stopped (i.e., time-to-pond). The time taken and the final water level in the watering can are recorded by the third person.

It is important to maintain the flow of water from the watering can as constant as possible during the entire measurement. To achieve this, large fluctuations in the water level in the watering pot should be avoided. Hence, the watering pot should be filled regularly. As a rule of thumb, the water level should not drop below 2/3 of the maximum level.

4.3 Calculations

First the calibration recordings of added water volume and water level are used to establish the relation between water level in the watering can and the volume of water in the can. This can be done by performing a simple regression in Excel, resulting in an equation of the form: Volume = a × Level. Using this equation, the measured water levels are then converted to volumes.

Time-to-pond measures which are characterized by comparable fluxes are valid for further analysis. Water flux is verified to be constant and outliers eliminated using:

$$Flux = \frac{V_{initial} - V_{final}}{t}$$

Where:

$Flux$ = speed of *flux* (l s^{-1})

$V_{initial}$ = water volume in watering can before measurement (l)

V_{final} = water volume in watering can after measurement (l)

t = time-to-pond (s)

4.4 Worked Example

To calibrate the watering can, a series of knows volumes of water is added to the watering can and the corresponding height in the watering can is recorded (Table 5). The relation between water level and volume is: Volume = 0.6317 × level (Figure 6).

Figure 3. A calibrated watering can.

Figure 4. Wire ring placed over the soil prior to commencing measurements.

Figure 5. Pouring water at the center of the ring from a height of 75 cm.

Table 5. Example of measurements to calibrate a watering can.

Water level (cm)	Water volume (l)
0	0
0.6	0.5
1.3	1
2.4	1.5
3	2
3.7	2.5
4.6	3
5.5	3.5
6.5	4
7.3	4.5
8	5
8.7	5.5
9.5	6
10.4	6.5
11.2	7
12	7.5
12.8	8
13.5	8.5
14.1	9
15	9.5
15.7	10
16.5	10.5

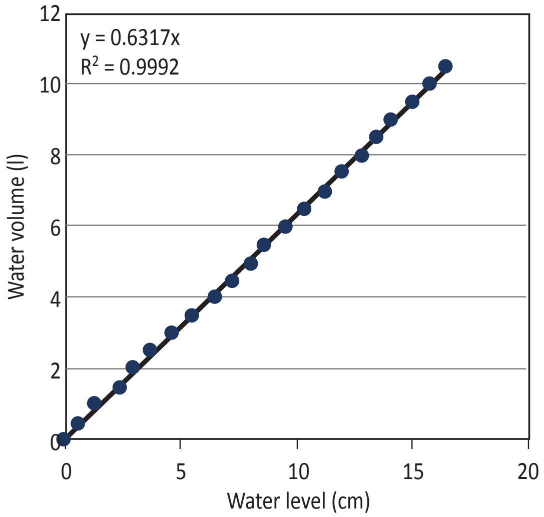

Figure 6. Regression of water volume and water level data.

In the field four different time-to-pond measurements were taken on a single test plot (Table 6).

The initial volume ($V_{initial}$) and the final volume (V_{final}) are calculated from the respective heights measured using the ruler calibrated watering pot.

So for the first replicate, V_{inital} was 12.64 l and V_{final} was 11.69 l. Therefore, the flux is calculated as:

$$Flux= \frac{V_{initial} — V_{final}}{t} = \frac{12.63\ \text{l} — 11.69\ \text{l}}{8.526\ \text{s}} = 0.11\ \text{l/s}$$

Table 6. Example of a time-to-pond measurement.

Replicate	Time to pond (s)	Initial height (cm)	Final height (cm)
1	8.526	20.00	18.50
2	6.916	18.50	17.00
3	9.200	10.00	8.00
4	8.666	16.00	15.10

5. References

Anderson, J.M., Ingram, J.S.I., 1993. Tropical Soil Biology and Fertility: A Handbook of Methods, (2nd edn). CAB International, Wallingford, pp. 221.

Barthes, B., Roose, E., 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. Catena. 47, 133–149.

Bouwer, H., 1986. Intake rate: Cylinder infiltrometer, in: Klute, A., Campbell, G.S., Jacson, R.D., Mortland, M.M., Nielsen, D.R. (Eds.), Methods of Soil Analysis. Part I, ASA and SSSA, Madison, WI, USA, pp. 825–843.

Brouwer, C., Prins, K., Kay, M., Heibloem, M., 1988. Irrigation water management: Irrigation methods. Training manual no 5. FAO Land and water development division, FAO, Rome.

Liu, C-W., Cheng, S-W., Yu, W-S., Chen, S-K., 2003. Water infiltration rate in cracked paddy soil, Geoderma. 117, 169–181.

Elrick, D.E., Reynolds W.D., Tan K.A., 1989. Hydraulic conductivity measurements in the unsaturated zone using improved well analyses. Ground Water Monit. Rev. 9, 184–193.

Govaerts, B., Sayre, K.D., Deckers, J., 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. Soil Till. Res. 87: 163–174.

Hellin, J., 2006. Better land husbandry: from soil conservation to holistic land management. Science Publishers, Enfield and Plymouth, 325 p.

Neave, M., Rayburg, S., 2007. A field investigation into the effects of progressive rainfall-induced soil seal and crust development on runoff and erosion rates: The impact of surface cover. Geomorphology 87, 378–390.

Reynolds, W.D., Elrick, D.E., 1990. Ponded infiltration from a single ring: I. Analysis of steady flow. Soil Sci. Soc. Am. J. 54, 1233–1241.

Reynolds, W.D., Elrick, D.E., Youngs, E.G., Amoozegar, A., 2002. Field methods (vadose and saturated zone techniques), in: Dane, J.H., Topp, G.C., (Eds.), Methods of soil analysis. Part 4. SSSA Book Series No. 5. SSSA, Madison, WI. pp. 817–826.

Walker, W.R., 1989. Guidelines for designing and evaluating surface irrigation systems, FAO, Rome.

Data Sheet – Small Ring Infiltration

Page ……./…….

Measurement date: ……../………/……….

Experiment: _____________________________

Plot	Measurement	Time to infiltrate 250 ml (s)

Data Sheet – Time-to-pond (TTP) **Page ……./…….**

Measurement date: ……../………/……….. Experiment: ____________________________

Plot	Replicate	Initial level (cm)	Final level (cm)	TTP (s)