

PENETRATION RESISTANCE

A Practical Guide for Comparing Crop
Management Practices



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For comments on how to improve, please contact
Bram Govaerts (b.govaerts@cgiar.org) or Nele Verhulst (n.verhulst@cgiar.org).

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Penetration resistance

1. Introduction

Penetration resistance is an indicator for the level of compaction of the soil. Compaction limits root growth and the availability of air and water to the roots (Herrick and Jones, 2002; Lampurlanés and Cantero-Martínez, 2003). A measure of penetration resistance is calculated by the resistance of a soil to the movement of a penetration cone divided by the penetration distance. Penetrometers can be either static or dynamic. Static penetrometers measure the force used to push a probe through the soil at a constant speed, while dynamic penetrometers measure penetration resistance through repeated impacts of a probe on the soil. This protocol deals with the use of a dynamic penetrometer. Herrick and Jones (2002) evaluated the practical use of both dynamic and static penetrometers and concluded that dynamic penetrometers are a reliable, durable and low cost tool for the assessment of soil compaction. Furthermore, the dynamic penetrometer can be used by inexperienced operators, such as extension workers or farmers. It must be noted that all penetrometers are sensitive to differences in moisture, bulk density and texture, so it is advisable to also measure these characteristics when using a penetrometer (Vaz and Hopmans, 2001; Herrick and Jones, 2002).

2. Materials and Equipment

- Penetrometer
- Datasheet and pencil

3. Procedure

If necessary remove straw or other debris from the soil surface to obtain a clear view of the depth indicator on the penetrometer. Hold the penetrometer perpendicular to the soil surface, and while this is important initially, if the angle of the penetrometer changes whilst you are taking measurements it should not be corrected. Take care to avoid soil irregularities, such as cracks. When operating the penetrometer, raise the sliding weight to its highest level and then drop it. Put your left hand straight on the handle, not around it (Figure 1) and be careful to ensure items and body parts are clear of the weight's sliding path to avoid any crushing injuries. In particular, always pull your right hand away from the device after dropping the weight, since it can be crushed under the weight when your hand follows the weight downward when working rapidly.

Record the number of impacts required to push the cone a pre-defined distance into the soil. This number will depend on soil characteristics, tillage depth, etc. Further, the increments used for this pre-defined distance must be relevant, and can for instance be based on the soil horizons. Assess the penetration resistance at different depths and take multiple measurements to ensure you are obtaining an accurate result.

For example, in an experiment at CIMMYT where plots were 13 m in length and 6 m (8 beds of 0.75 m) in width, four measurements were taken, with two in bed 3 and two in bed 6. The used depth increments were 15 cm: 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm depth.



Figure 1. Use of the penetrometer: Left: the weight is raised all the way to the top of the penetrometer; Right: the weight is dropped and one impact is counted.

4. Calculations

Penetration resistance is calculated with the following formula:

$$R = \frac{(N \times M \times g \times SD)}{(A \times PD)}$$

Where:

R = the penetration resistance (Pa)

N = the number of impacts

M = the mass of the sliding weight (kg)

g = the gravity = 9.81 m/s^2

SD = the sliding distance of the hammer (m)

A = the surface area of the cone (m^2)

PD = the penetration distance (m)

The surface area of the cone is calculated as:

$$A = \pi \times r \times s$$

Where:

A = the surface area of the cone (m^2)

r = the radius of the cone (m)

s = the longitudinal length of the cone (m)

5. Worked Example

The measurement was undertaken using a penetrometer that has a cone with a radius of $r = 0.895 \text{ cm}$ and a height of $h = 3.58 \text{ cm}$. The mass of the impact is 5 kg , the sliding distance of the hammer is 29.5 cm and the penetration distance 15 cm .

For the surface area of the cone:

$$s^2 = r^2 + h^2 = 0.895^2 + 13.62^2 = 13.62 \text{ cm}^2$$

$$s = 3.69 \text{ cm}$$

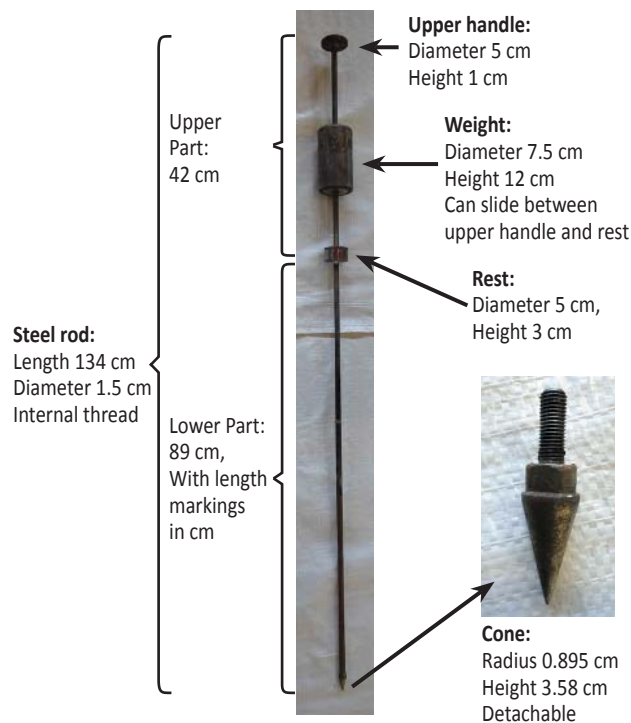
$$A = \pi \times r \times s = 10.38 \text{ cm}^2$$

The penetration resistance is:

$$R = \frac{(N \times M \times g \times SD)}{(A \times PD)} = \frac{(15 \times 5.0 \times 9.81 \times 0.295)}{(10.38 \times 10^{-4} \times 0.15)} = 1.4 \text{ MPa}$$

6. Penetrometer specifications

A penetrometer can be constructed by a skilled metal worker; therefore, specifications of a penetrometer are given here. When constructing a penetrometer, the dimensions do not have to be exactly the same; this is an example of the penetrometer used at CIMMYT. It is, however, very important to know all the exact dimensions of the penetrometer, especially the cone, in order to make correct calculations.



7. References

- Herrick, J.E., Jones, T.L., 2002. A dynamic cone penetrometer for measuring soil penetration resistance. *Soil Sci. Soc. Am. J.* 66, 1320–1324.
- Lampurlanés, J., Cantero-Martínez, C., 2003. Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. *Agron. J.* 95, 526–536.
- Vaz, C.M.P., Hopmans, J.W., 2001. Simultaneous measurement of soil penetration resistance and water content with a combined penetrometer–TDR moisture probe. *Soil Sci. Soc. Am. J.* 65, 4–12.

8. Useful Reading

- Limon-Ortega, A., Sayre, K.D., Drijber, R.A., Francis, C.A., 2002. Soil attributes in a furrow-irrigated bed planting system in Northwest Mexico. *Soil Tillage Res.* 63, 123–132.

Measurement date:/...../.....

Experiment: _____

Plot	Measurement	Depth	Number of impacts
	1	1	
	1	2	
	1	3	
	1	4	
	2	1	
	2	2	
	2	3	
	2	4	
	3	1	
	3	2	
	3	3	
	3	4	
	4	1	
	4	2	
	4	3	
	4	4	

