Jour. Agric. Physics, Vol. 1, No. 1, pp. 93-97 (2001)

Measuring Physical Parameters Characterising Soil and Plant

R. P. TRIPATHI
Department of Soil Science, G. B. Pant University of Agriculture & Technology, Pantnagar 263145 (Uttaranchal)

ABSTRACT

Concept of measurement and need for basic understanding of soil physical phenomena for precise measurements are discussed. Emphasis has been given on what is being measured and what is needed. Some possible operational techniques to improve precision in the existing methods have been described particularly for bulk density and soil hydraulic conductivity measurements. A simple technique to reduce possible errors during sampling of plant parts and measurement of xylem water potential is described. Need for standardization among different laboratories and research groups is emphasized for a coordinated and collective effort in developing research techniques and various indices for characterizing soil physical and edaphological processes.

Introduction

Measurement refers to quantification of a property of the material to answer a specific question. In dynamic systems like soil and plants the answer may depend not only on the end value of the property under investigation but also on the steps used in the measurement. For example, for measuring saturated hydraulic conductivity (Ks) two soil cores were collected from the field carefully preserving the original structure. The inner surface of one metal core cylinder was smeared with grease whereas the other one was not greased. Even if the two soil cores were nearly isotropic and homogeneous boundary flow of water along the cylinder walls in the ungreased metal core would lead to higher Ks than that in the greased one. The concept of measurement, thus, includes both the steps used in making the measurement and the purpose of measurement. The practical questions are generally simple but the answers often involve comprehensive experimentation and complex measurement techniques. A comprehensive description of methods for characterization of soil physical parameters is given in Methods of Soil Analysis, Part 1 ; Edited by Klute (1986). For this reason only a conceptual aspect of measurement of some properties such as soil structure, hydraulic conductivity, sorptivity and plant water potential are discussed in this paper.

Soil structure

Soil structure refers to arrangement of the solid phase of the soil and its pore space located between its constituent particles (Marshall and Holmes, 1979).

Existing methods of characterization of soil structure : The existing common methods of characterization of soil structure can be grouped into 3 broad categories (Dexter, 1997).

(i) *Structural State* : The structural state of soil has been characterized generally in terms of bulk properties of soil such as bulk density, mean weight diameter of aggregates, porosity, water content and cone penetration resistance. These properties infact describe the soil conditions whether loose or compact, cloddy or porous, wet or dry but not the arrangement of particles per se. In addition, these quantities do not have common basis and are not additive and, therefore, it is difficult to develop mathematical relations for quantifying the state or behaviour of soil. These methods of characterization are, therefore, weak.

(ii) *Structure dependent soil property distribution*: These include measurement of aggregate size distribution, pore-size distribution, water retention characteristics etc. as a measure of soil structure. Estimation of pore-size distribution is normally done from water retention data, using capillary rise model, in the wet range of the soil water characteristic curve. The results of such characterizations provide a better description of soil structure and, therefore, are one step superior to the methods mentioned in category (i) but still not ideal as per the definition.

(iii) *Process oriented structure - derived properties* : These include fluid transmission characteristics. Fluid transmission pattern is one of the most important consequence of structure and, therefore, such methods are much better than those listed under categories (i) and (ii) However, these methods involve more complex characterization in the field. In addition most methods currently in use are either destructive in nature (e.g. core sampling) or induce soil structural changes during the measurement (e.g. infiltration test etc.).

Owing to relatively easy characterization of bulk properties of soil considerable work has been done on penetrometer, and micromorphometric techniques which determine fractal geometry (Dexter, 1997).

(iv) *Cone penetration resistance* : The cone penetration resistance is related with soil mechanical impedance to seedling emergence or root penetration and, therefore, it is an important structural state of the soil. Modern penetrometers record both the depth of the cone below the soil surface and the corresponding resistive force. However, relations of crop root growth to soil resistance to penetration show that the limiting soil strength value for root extension as measured by a cone penetrometer can be 4 to 8 times higher than the maximum force that roots can exert (Barley and Greacen, 1967, Macariola and Woodhead, 1994). This is perhaps because roots can follow cracks, macropores and biopores while metal probes are confined to move in straight lines. The pressure exerted at the tips of elongating roots may vary from 0.1 to 1.2 MPa and is species dependent (Macariola and Woodhead, 1994). In addition, the cone penetration resistance values are highly dependent on bulk density and water content (Fig. 1), soil texture and degree of soil aggregation (Hadas, 1997). Greater is the transpiration demand, lower is the limiting value of soil impedance for root elongation (Fig. 2). Thus the cone penetration resistance values are not only far from the actual resistance encountered by plant roots but are also not unique and depend on a number of parameters. The penetrometer should be frequently calibrated using known weights and cones should be examined for wear and damage every day.

(v) *Fracture surface* : A good assessment of structural condition of the soil can be made from the morphology of the fracture surface (Fig. 3). Differences in fracture surfaces arise due to distribution of joints and pre-existing planes of weakness. The fracture surfaces of a soil under grass-sod for many years will be very rough because of high aggregation, whereas surface of a sodic clay will be extremely smooth because of no structure on size-scales longer than the individual clay particles.

An accurate measurement of soil structure/pore patterns in terms of size, shape, continuity irregularity and orientation of soil pores, biopores, length of cracks and other flows as they exist in the soil and affect all physical process important to plant is possible through micro-morphometric techniques (Dexter, 1997). The micromorphometric techniques based on image analysis of undisturbed samples provides a visual appreciation of pore patterns in the soil. The pores are selected for measurement according to their shape such as rounded or regular pores, irregular pores, elongated pores etc. Pores of each shape group can be further sub-divided into a selected number of size classes. Sum of the values of pores of each shape group represents the total porosity. Nuclear magnetic resonance imaging technology would help to directly estimate length of existing flaws and cracks and *in situ* arrangement of soil units (Dexter, 1997).

Mathematical quantification of structural state

A simple mathematical description of soil structural state can be derived if the properties measured to characterize the structural state are transformed into a single system. A more rational system could be one based on specific volume and void ratio which are not only additive but easy to measure (Dexter, 1997). Total volume of a soil (V soil) can be expressed as sum of volumes of (V_s), water (V_w), and air (V_a) as :

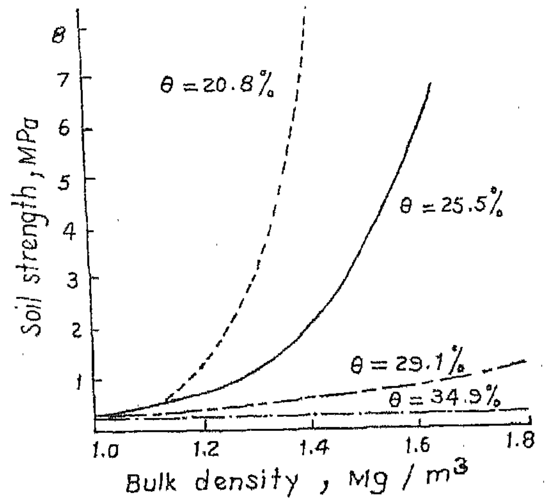

Fig. 1. Soil strength as a function of bulk density and soil water content, (Kandasamy, 1981).

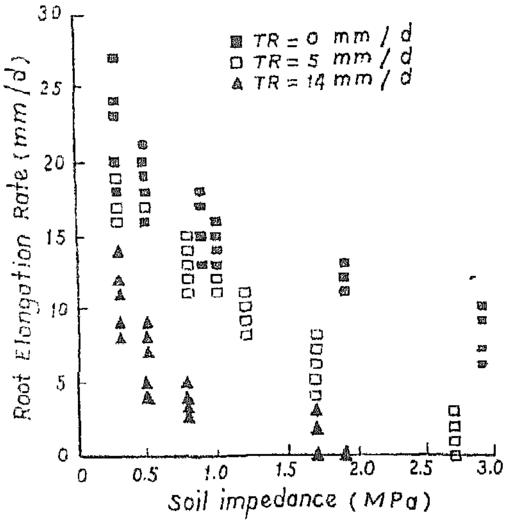

Fig. 2. Root elongation rates as a function of transpiration rate and soil impedance to penetration (Gupta et al., 1990).

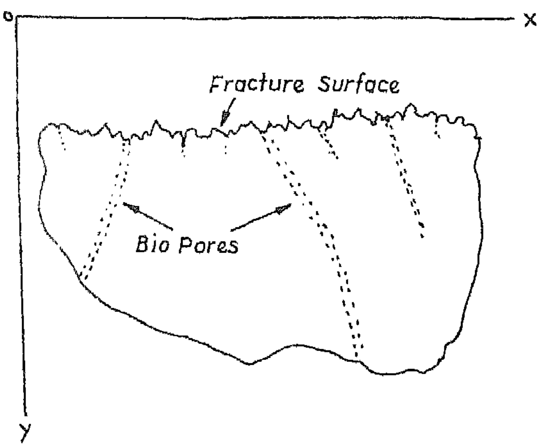

Fig. 3. Schematic representation of a soil clod showing fracture surface, biopores and microcracks.

$$V_{soil} = V_s + V_w + V_a$$

Dividing the above equation by V_s results specific volume of soil (R_{soil}) as :

$$R_{soil} = 1+R_w+R_a \quad \text{or} \quad R_{soil} = 1+e \qquad ....(1)$$

where R_w and R_a are water and air ratios, respectively, and e is void ratio. Such a characterization is useful both in swelling and non-swelling soils. For example when a non-swelling soil is wetted, water displaces an equal volume of air and

$$R_{soil} = \text{constant, and } \Delta R_w = -\Delta R_a \qquad ....(2)$$

Similarly, when a swelling soil is wetted R is almost constant in the normal swelling range, so that

$$\Delta R_{soil} \cong \Delta R_w \qquad ....(3)$$

A plot of e against R_w will describe swelling and shrinkage characteristics

When a soil is compressed with a reduction in its air-filled pore space and without water, then

$$\Delta R_{soil} = \Delta R_a \qquad ......(4)$$

R_a can also be splitted into the air ratios for cracks, R_1, worm holes, R_2, interaggregate pores, R_3, intra-aggregate pores, R_4 etc. In the same way R_w can also be subdivided. All these quantities are additive and transform the bulk properties of soil into a single system which contains useful structural information.

Hydraulic conductivity

Hydraulic conductivity is estimated indirectly by pore-size distribution models (Childs and Collis-George, 1950, Marshall, 1958, Millington and Quirk, 1959) and directly by various steady state and transient flow methods (Klute, 1986). The steady state methods are accurate but time consuming and are useful only in the wet soil moisture regimes. The transient techniques are not only time consuming but are complex and involve lengthy calculations. The calculations, however, have now become easy and fast through use of computers.

The saturated hydraulic conductivity, Ks, is highly sensitive to presence of cracks, macropores and bio-pores. It is for this reason that water in soil profile rarely flows as a homogeneous front but follows irregular shaped pathways bypssing the unsaturated matrix. This bypass flow in significant in swelling-shrinking soils and in puddled rice soils. The macropores or cracks allow the rain or irrigation water to percolate deeper in the profile leaving the upper part unsaturated. Depth of vertical macropore continuity is important in determining the pathways of water flow in the soil profile.

In a simplest way, depth and abundance of cracks and macropores can be determined by staining the pores with a water-soluble white paint. The techniques based on fractal geometry are most suitable in determining such pore patterns. Since cracking depends on soil water content bypass flow should be determined at different initial water contents. The bypass flow can be measured as bypass flow ratio (Wopereis, 1994).

Sorptivity

A reliable measurement of sorptivity of soils or soil aggregates is possible through use of disc permeameters or tension infiltrometers (Leads-Harrison et al., 1994 ; Nachabe and Illangasekare, 1994). The experimental set-up is similar to horizontal infiltration method of Bruce and Klute (1956) for determining soil water diffusivity (Fig. 4). Water is allowed to enter into the soil column under suction so that it does not fill the macropores. In the laboratory, X-ray CAT scanning, with a special resolution of 1 mm to 20 μm can be used to follow the water absorption into soil samples (Fig. 4).

Xylem water potential

The simplest direct method of measurement of xylem water potential (XWP) is through pressure chamber technique (Scholander *et al.,* 1965). Since the effect of pressure on water potential is thermodynamically equivalent to the effect of solutes and other components of water potential, the pressure at equilibrium has been used as a measure of water potential. The pressure chamber has found increasing use as a field instrument for measuring plant water potential. The use is made of excised part of the plant material placed in the pressure chamber. When the plant material is severed the xylem sap which is under-tension recedes from the cut end. Amount of pressure at which cell sap returns to the cut surface is regarded as XWP of the tissue before it was excised. The XWP is related to plant water potential Ψ as,

$$\Psi = XWP + \Psi s$$

where XWP is negative component of the water potential of xylem sap measured as positive pressure in the pressure chamber and Ψs is the *osmotic potential of xylem sap. Ψ is directly* estimated from XWP for negligible Ψs.

Measurements have shown a decrease in XWP due to desiccation during and after excision of plant parts and measurement by the pressure chamber technique (Gardner and Tanner 1976, Bahadur and Tripathi, 1995). Bahadur and Tripathi (1995) reported that XWP of wheat (*Triticum aestivum* L.) leaf samples collected in paper bag remained unaltered for 180 sec. during the morning (7-7.30 AM) at Pantnagar (Fig. 5). At noon (1-1.30 PM) an error of 0.15 MPa in leaves collected in the paper bag and 0.3 MPa in uncovered leaves was recorded in 120 sec. after the excision. Sampling in paper bag and sheltering the instrument at the field site by umbrella was most appropriate.

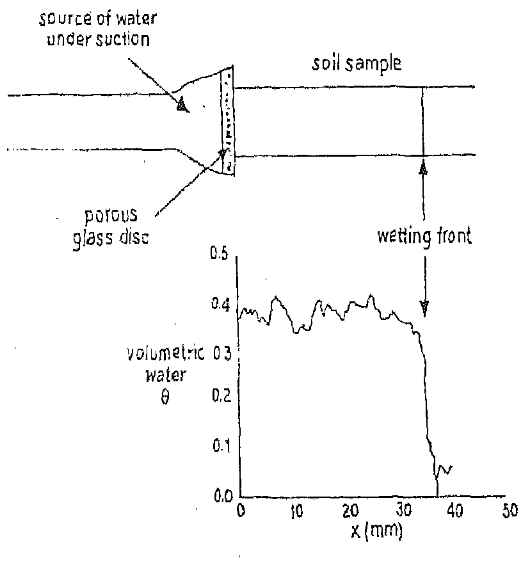

Fig. 4. Infiltration into a horizontal soil column (top), and the corresponding profile of water content, q, after 1000S as determined by X-ray CAT scanning (Dexter, 1997).

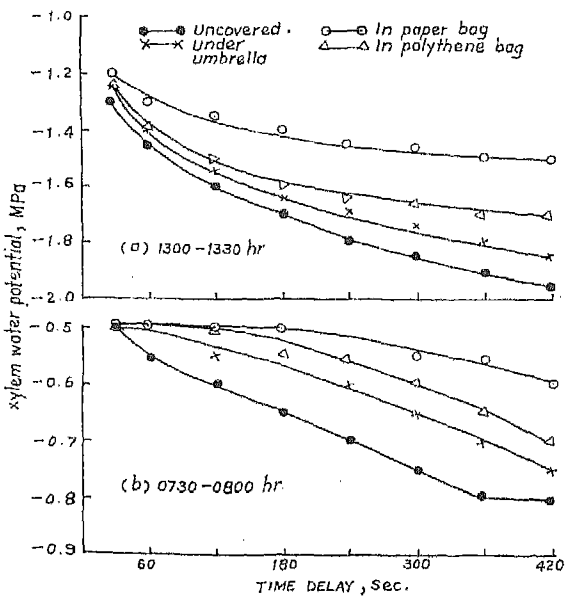

Fig. 5. Effect of time delay between excision of leaf and its placement in the pressure chamber on xylem water potential (Bahadur and Tripathi, 1995).

Errors and suggestions

Two types of errors are common in soil physical measurements - first the system errors related with the experimental set up and the measurement technique and second is the sampling errors related with sampling procedure, soil condition, sample size, and sample homogeneity. The decision regarding collection of whether disturbed or undisturbed sample will depend on purpose of the sampling. Sampling induced compaction, soil settlement and cracking in undisturbed samples will change bulk density, pore-size distribution and transmission characteristics of soil. This implies that soil metal friction during core sampling should be minimum and the application of force on the sampler should be continuous and slow enough to cause least disturbance when the sampler is pushed into the soil. Greasing the inner wall of the metal core facilitates sliding of the soil in the core cylinder. Also sampling in a dry soil will always lead to disturbance of the original structure and, therefore, optimum wetness in the field should be ensured to reduce soil-metal friction. Similarly sampling procedures would be different for puddled and non-puddled soils.

Most soil physical measurements require the insertion of sensors which disturb the soil and alter the property being measured. Efforts should be made to minimize these disturbances. Details of environment of the sensors is generally not known and, therefore, replicate measurements of each property is essential to find out a reliable mean value, and standard diviation as a measure of heterogeneity.

The size scale of physical measurements, must be appropriate for the characteristics being studied. For example for a tilled layer the size-scale may be depth of the layer (≅150-200 mm) and for the processes within the tilled layer the size-scale may be aggregate (≅10 mm). Similarly for the processes involving root axis, the size-scale may be root diameter (≅1 mm). At each size scale, specific measurement techniques are needed. Erroneous conclusions may be drawn if measurements at different size scales are combined.

A large number of professionals in the country are working on development of improved techniques to characterize the soil physical environment. It would be pertinent to establish coordination among different professionals, laboratories and research groups for a collective effort in improving and developing new research techniques.

References

Bahadur, R. and Tripathi, R.P. 1995. Sampling procedure for measurement of xylem-water potential by pressure-chamber technique. *Indian J. Agric. Sci.* **65** : 830-831.

Bruce, R.R. and Klute, A. 1956. The measurement of soil-water diffusivity. *Proc. Soil Sci. Soc. Am.* **20** : 458-462.

Barley, K.P. and Greacen, E.L. 1967. Mechanical resistance as soil factor influencing the growth of roots and underground shoots. *Adv. Agron.* **19** : 1-43.

Childs, E.C. and Collis-George, N. 1950. The permeability of porous materials. *Proc. Roy. Soc.* **201**A : 392-405.

Dexter, A.R. 1997. Physical properties of tilled soils. *Soil Tillage Res.* **43** : 41-63.

Gardner, P.W. and Tanner, G.B. 1976. Potato leaf and tuber water potential measurements with a pressure chamber. *American Potato J.* **53** : 1-14.

Gupta, S.C., Hadas, A., Voorhees, W.B., Wolf, D., Larson, W.E. and Sharma, P.P. 1990. Development of guidelines on the susceptibility of soils to exessive compaction. Final Report submitted to the Binational Agricultural Research and Development Fund (BARD). *Bat Dagan, Israel*, p. 294.

Hadas, A. 1997. Soil tilth - the desired soil structural state obtained through proper soil fragmentation and reorientation Processes. *Soil Tillage Res.* **43** : 7-40.

Kandasamy, A. 1981. Soil strength and rice roots. M.S. thesis, University of the Philippines. Las Banos Pilippines.

Klute, A. (Ed.). 1986. Methods of soil analysis, Part 1, Physical and mineralogical methods. American Society of Agronomy, Publ. No. 9, Madison, USA, p. 1188.

Leads,-Harrison, P.B., Youngs, E.G. and Uddin, B. 1994. A device for determining the sorptivity of soil aggregates. *Eur. J. Soil Sci.* **45** : 269-272.

Macariola, N.R. and Woodhead, T. 1994. Soil penetration resistance p. 58-64 In Soil Physical Properties : Measurement and use in rice-based cropping systems. Editors M. Wopereis, M. Kropff, J. Bouma, A. Van Wijk and T. Woodhead. IRRI, Publication, Los Banos, Philippines.

Marshall, T.J. 1958. A relation between permeability and size distribution of pores. *J. Soil Sci.* **9** : 1-8.

Marshall, T.J. and Holms, J.M. 1979. Soil Physics. Cambridge University Press. London, U.K. p. 345.

Millington, R.J. and Quirk, J.P. 1959. Permeability of Porous media. *Nature*, **183** : 387-388.

Nachabe, M.H. and Illiongasekare, T. 1994. Use of tension infiltrometer data with unsaturated hydraulic conductivity models. *Ground Water.* **32** : 1017-1021.

Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hammingsen, E.A. 1965. Sap pressure in vascular plants. *Science*, **148** : 399-346.

Wopereis, M.C.S. 1994. Field monitoring techniques - soil water interactions, p. 37-39 In Soil Physical Properties : Measurement and use in rice-based cropping systems. Editors. M. Wopereis, M. Krooff, J. Bouma, A. Van Wijk and J. Woodhead. IRRI Publication, Los Banos, Philippines.