5

Soil Water Characteristics and Behavior

When the earth will . . . drink up the rain as fast as it falls.
—*H. D. Thoreau*, The Journal

Ch. 6

Hydrosphere

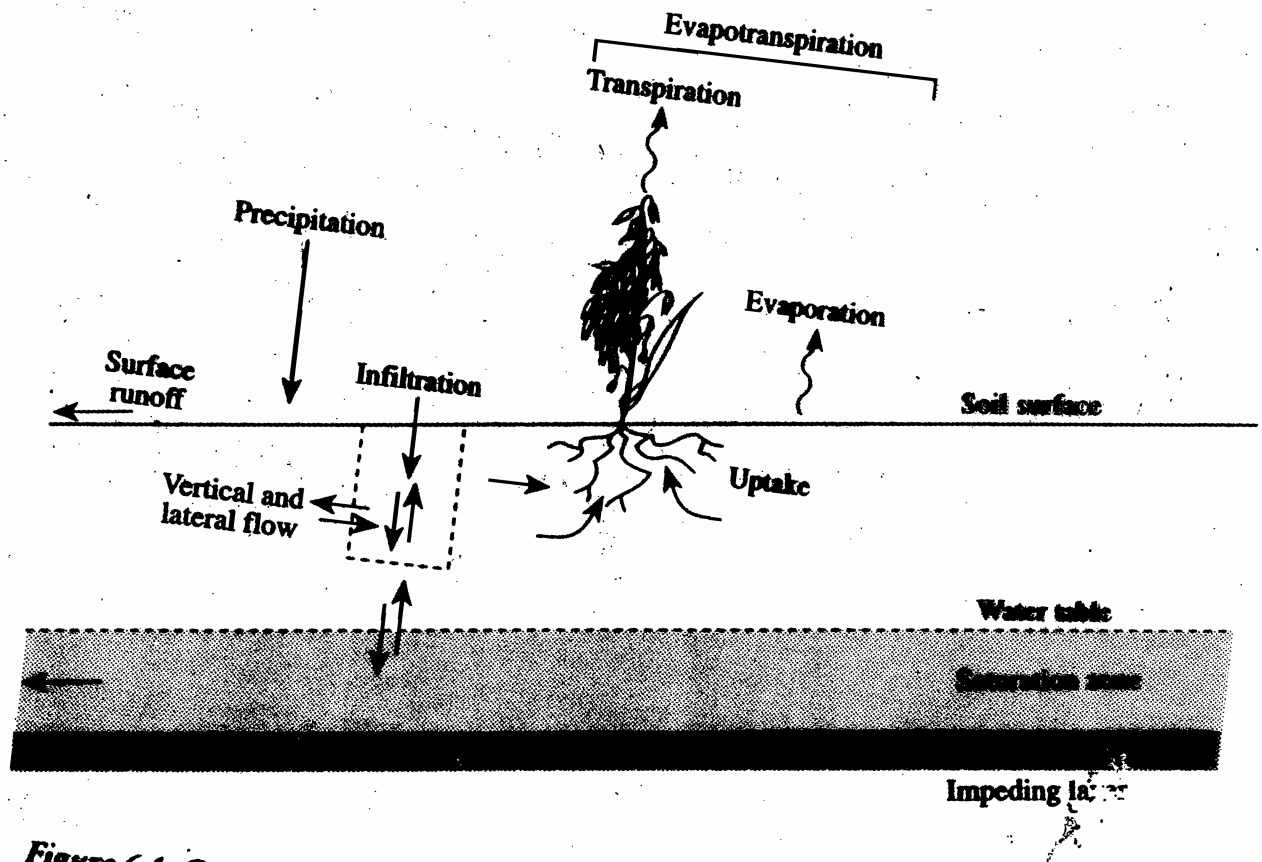


Figure 6.1 Components of the hydrological cycle in relation to the soil layer (from Singer and Munns 1991)

Hygroscopic

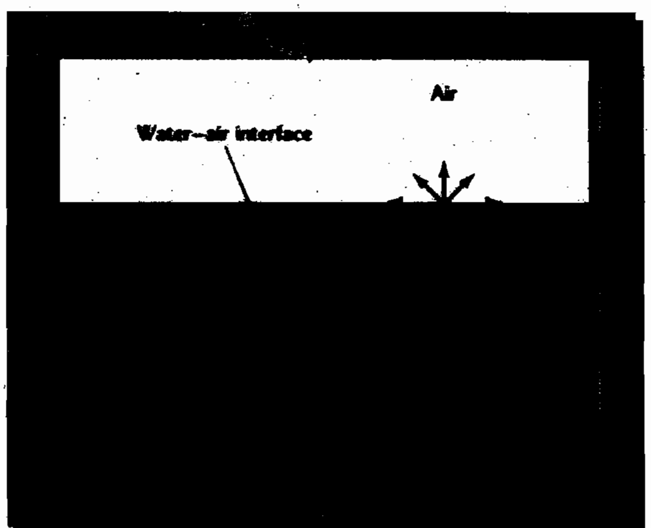


FIGURE 5.3 Comparative forces acting on water molecules at the surface and beneath the surface. Forces acting below the surface are equal in all directions since each water molecule is attracted equally by neighboring water molecules. At the surface, however, the attraction of the air for the water molecules is much less than that of water molecules for each other. Consequently, there is a net downward force on the surface molecules, and the result is something like a compressed film or membrane at the surface. This phenomenon is called *surface tension*.

– Surface tension is also able to do work

Force/length

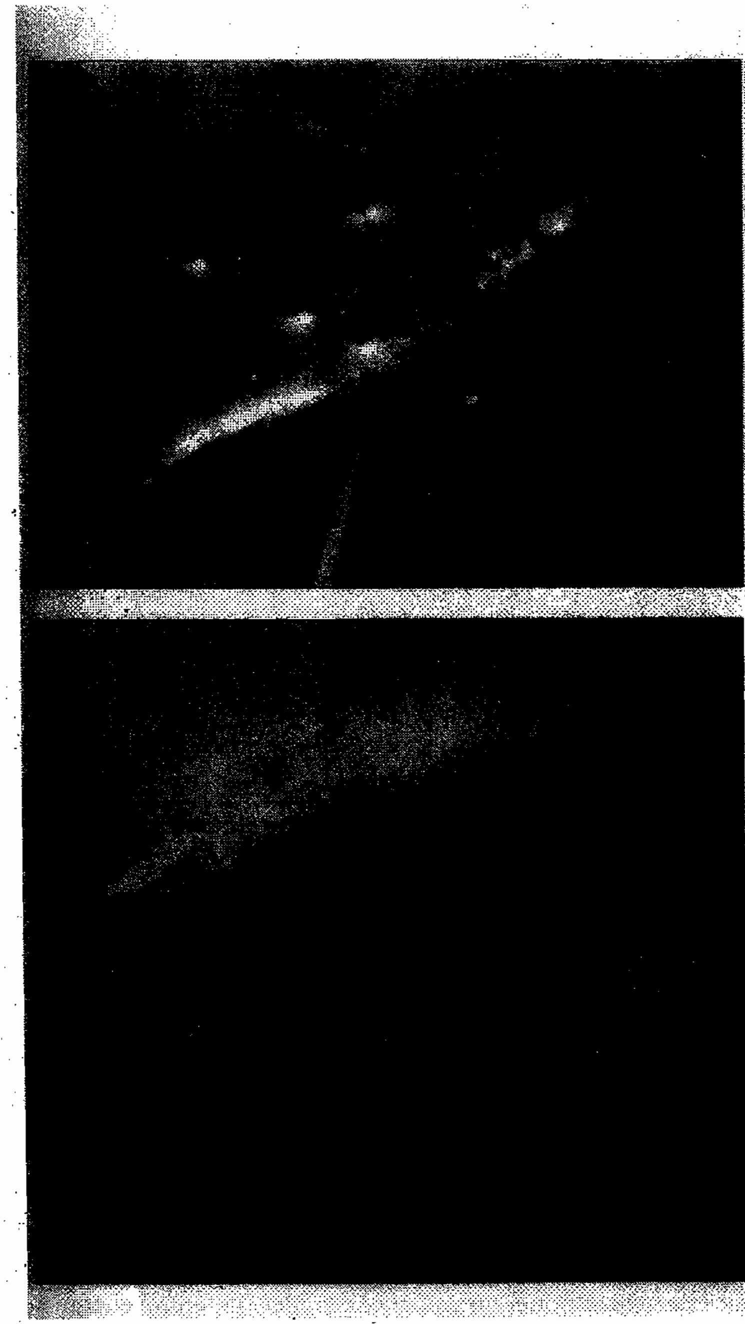
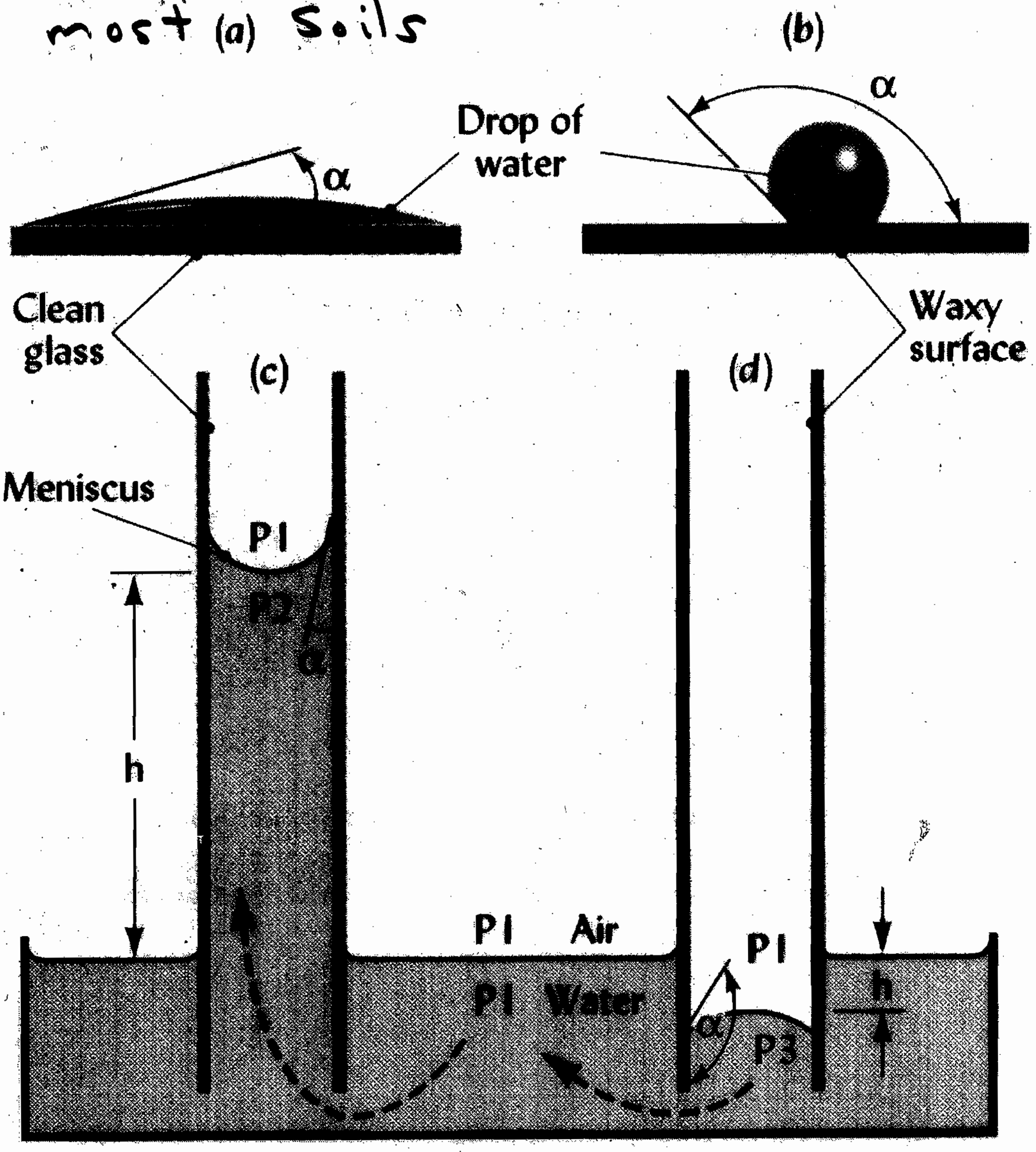


FIGURE 5.4 Everyday evidences of water's surface tension (above) as insects land on water and do not sink, and of forces of cohesion and adhesion (below) as a drop of water is held between the fingers. (Photos courtesy of R. Weil)

water in most soils



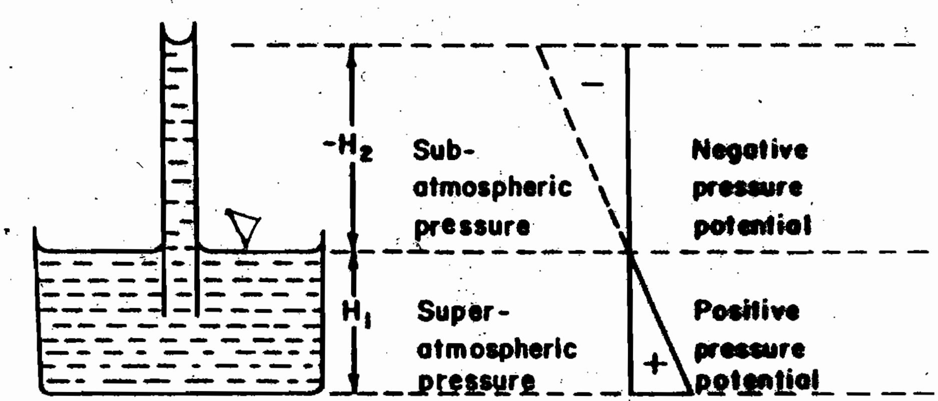
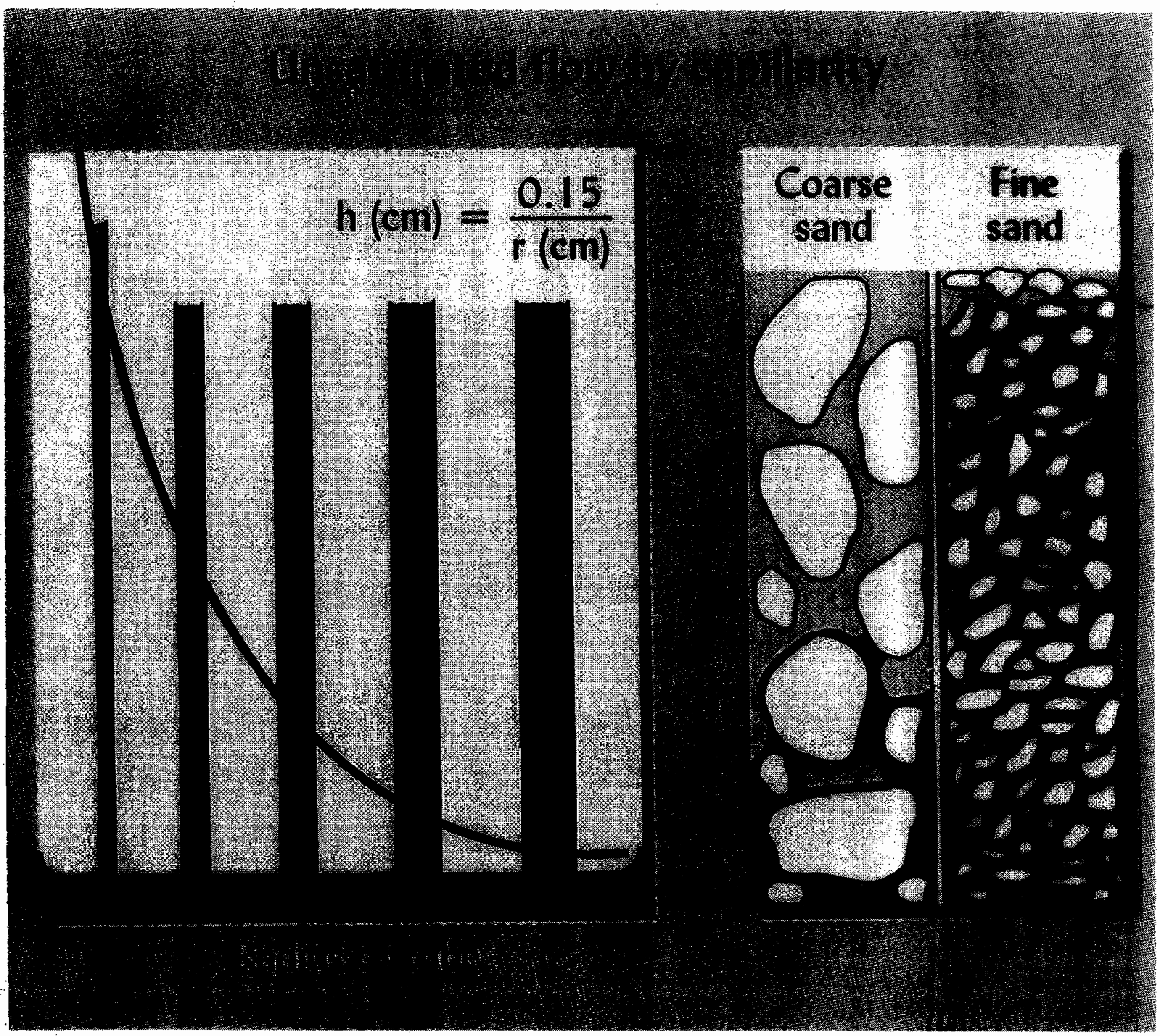


Fig. 7.5. Superatmospheric and subatmospheric pressures below and above a free-water surface.

Capillarity

$$h = \frac{2\sigma\cos\theta}{\rho g r}$$



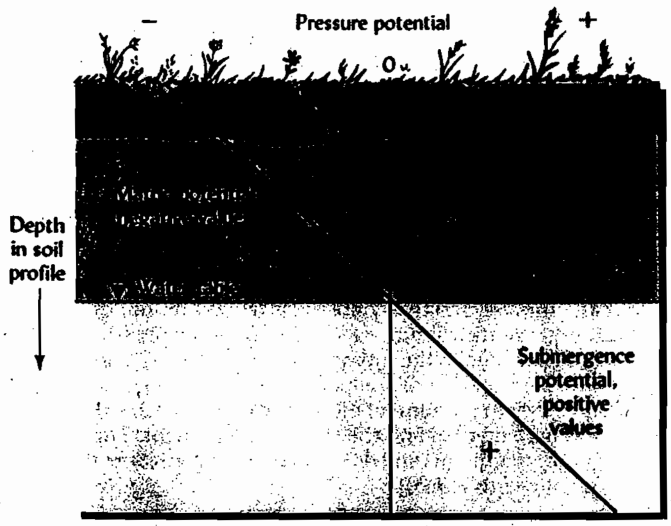
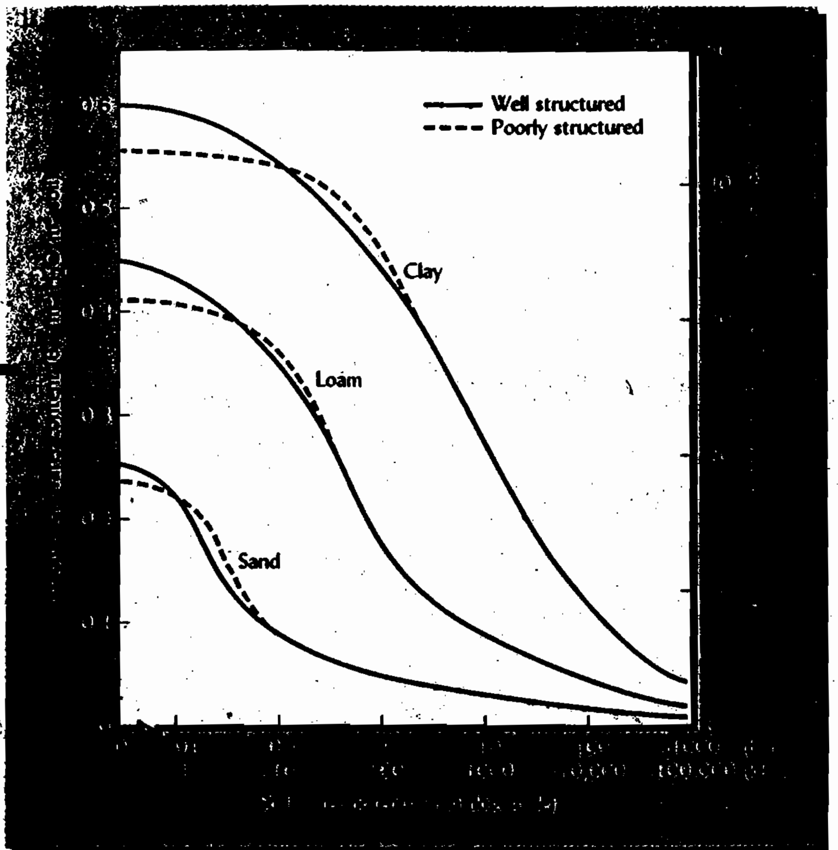


FIGURE 5.10 The matric potential and submergence potential are both pressure potentials that may contribute to total water potential. The matric potential is always negative and the submergence potential is positive. When water is in unsaturated soil above the water table (top of the saturated zone) it is subject to the influence of matric potentials. Water below the water table in saturated soil is subject to submergence potentials. In the example shown here, the matric potential decreases linearly with elevation above the water table, signifying that water rising by capillary attraction up from the water table is the only source of water in this profile. Rainfall or irrigation (see dotted line) would alter or curve the straight line, but would not change the fundamental relationship described.

$$\Psi_T = \Psi_M + \Psi_O + \Psi_G \ldots$$

Φ



ψ

FIGURE 5.12 Soil water potential curves for three representative mineral soils. The curves show the relationship obtained by slowly drying completely saturated soils. The dashed lines show the effect of compaction or poor structure. The soil water potential ψ (which is negative) is expressed in terms of bars (upper scale) and kilopascals (kPa) (lower scale). Note that the soil water potential is plotted on a log scale.

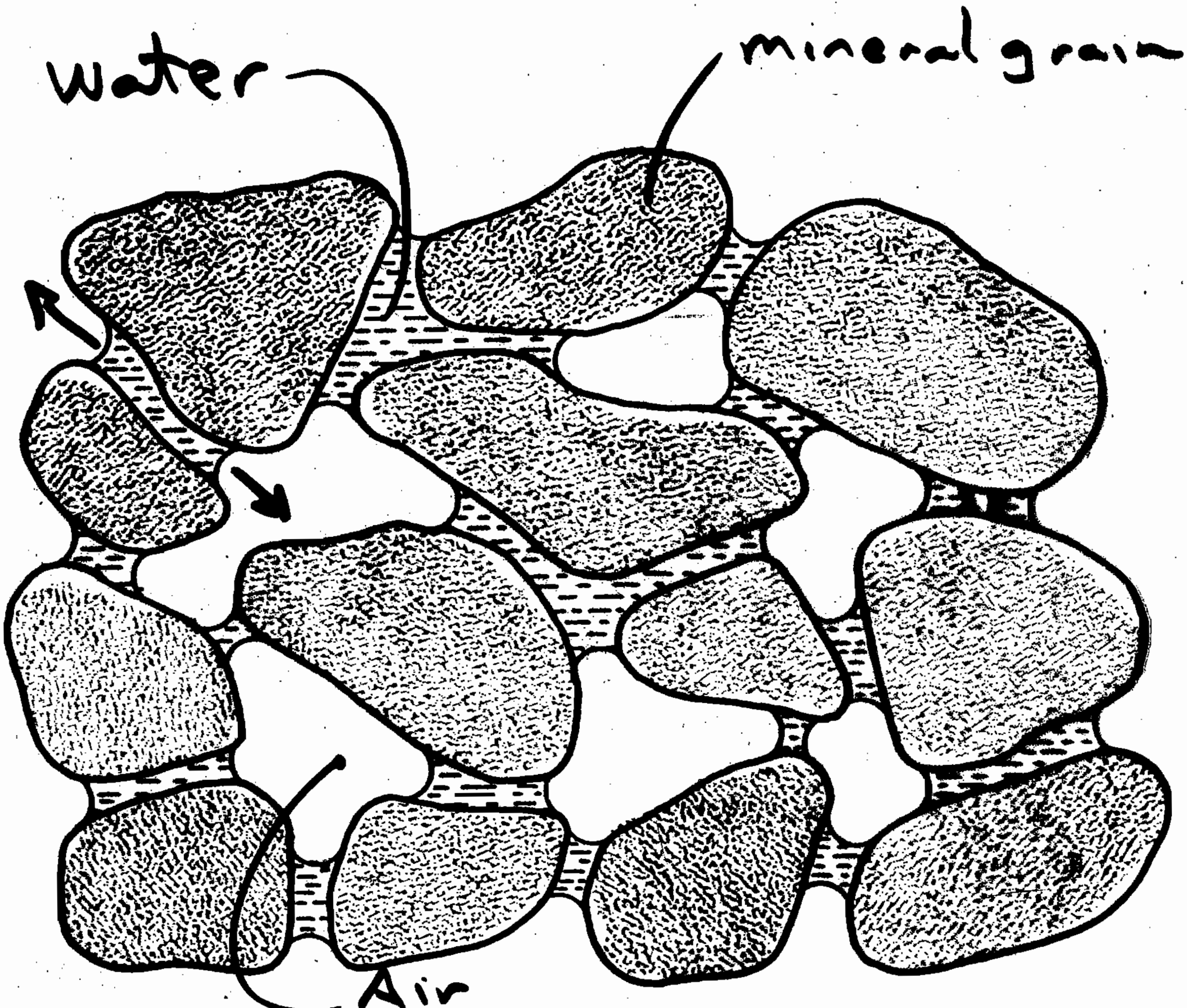
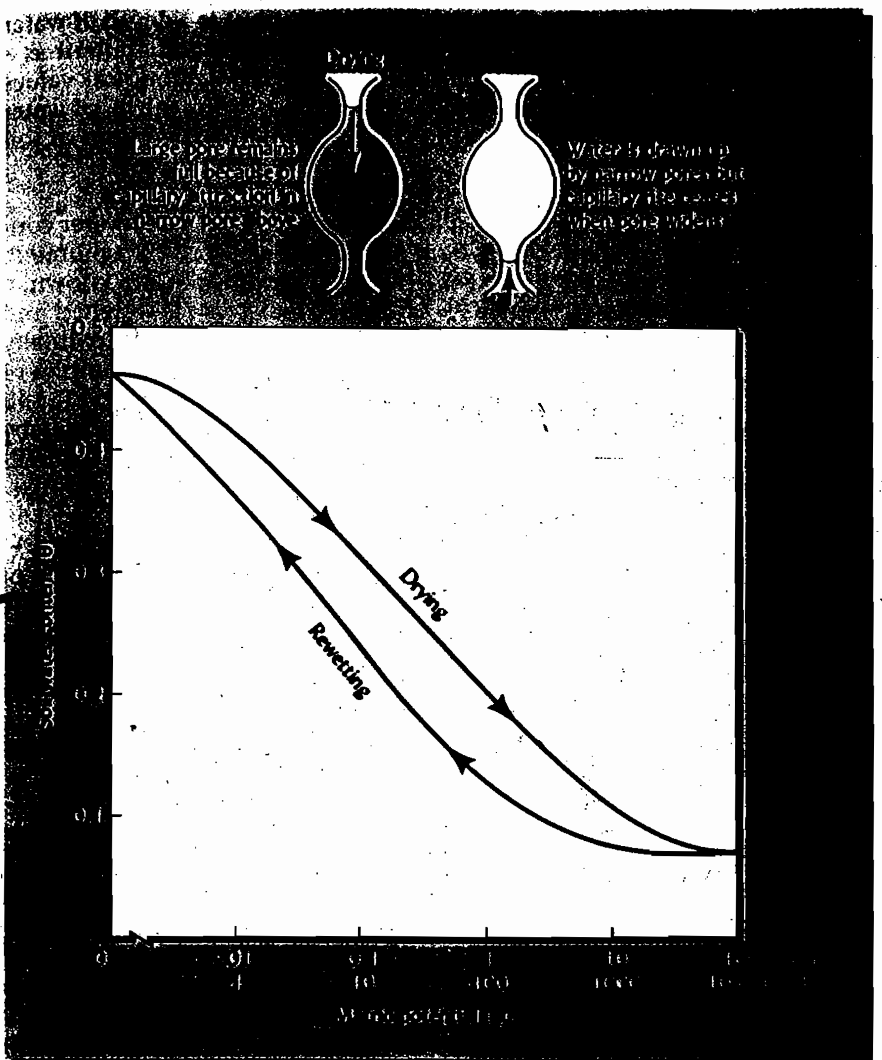


Fig. 9.1. Water in an unsaturated coarse-textured soil.

Capillarity



ϕ

ψ

FIGURE 5.13 The relationship between soil water content and matric potential of a soil upon being dried and then rewetted. The phenomenon, known as hysteresis, is apparently due to factors such as the nonuniformity of individual soil pores, entrapped air, and the swelling and shrinking that might affect soil structure. The drawings show the effect of nonuniformity of pores.

FIGURE 5.14 A cutaway view of a commercial gypsum electrical resistance block placed about 45 cm below the soil surface. Thin wires lead from the block to the surface, where they can be connected to a resistance meter. For most applications several blocks should be buried at different depths throughout the root zone. (Photo courtesy of R. Weil)

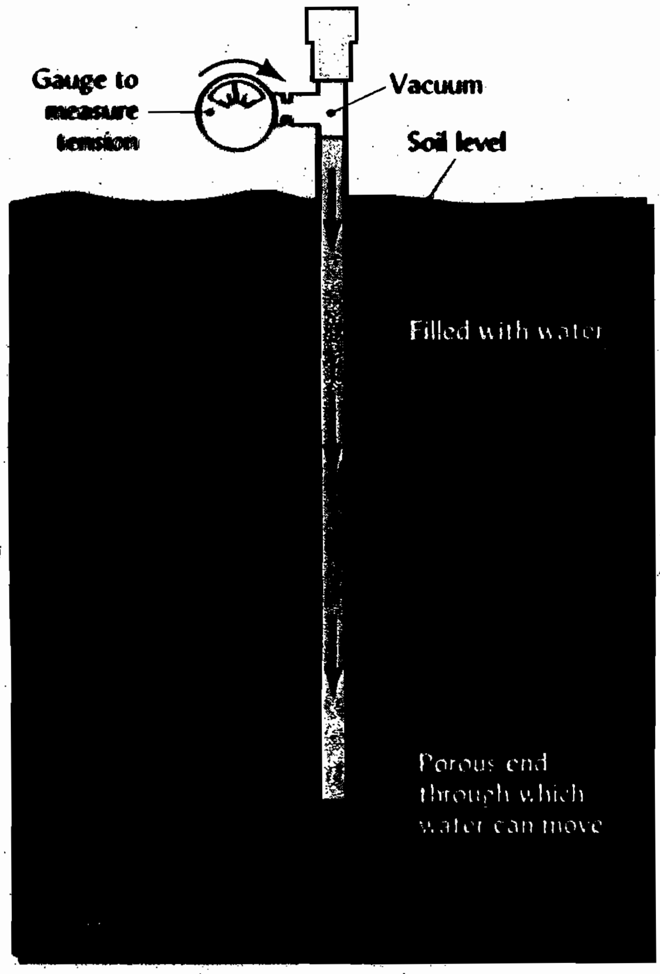


FIGURE 5.17 Tensiometer method of determining water potential in the field. Cross section showing the essential components of a tensiometer. Water moves through the porous end of the instrument in response to the pull (matric potential) of the soil. The vacuum so created is measured by a gauge that reads in kPa of tension (–kPa water potential).

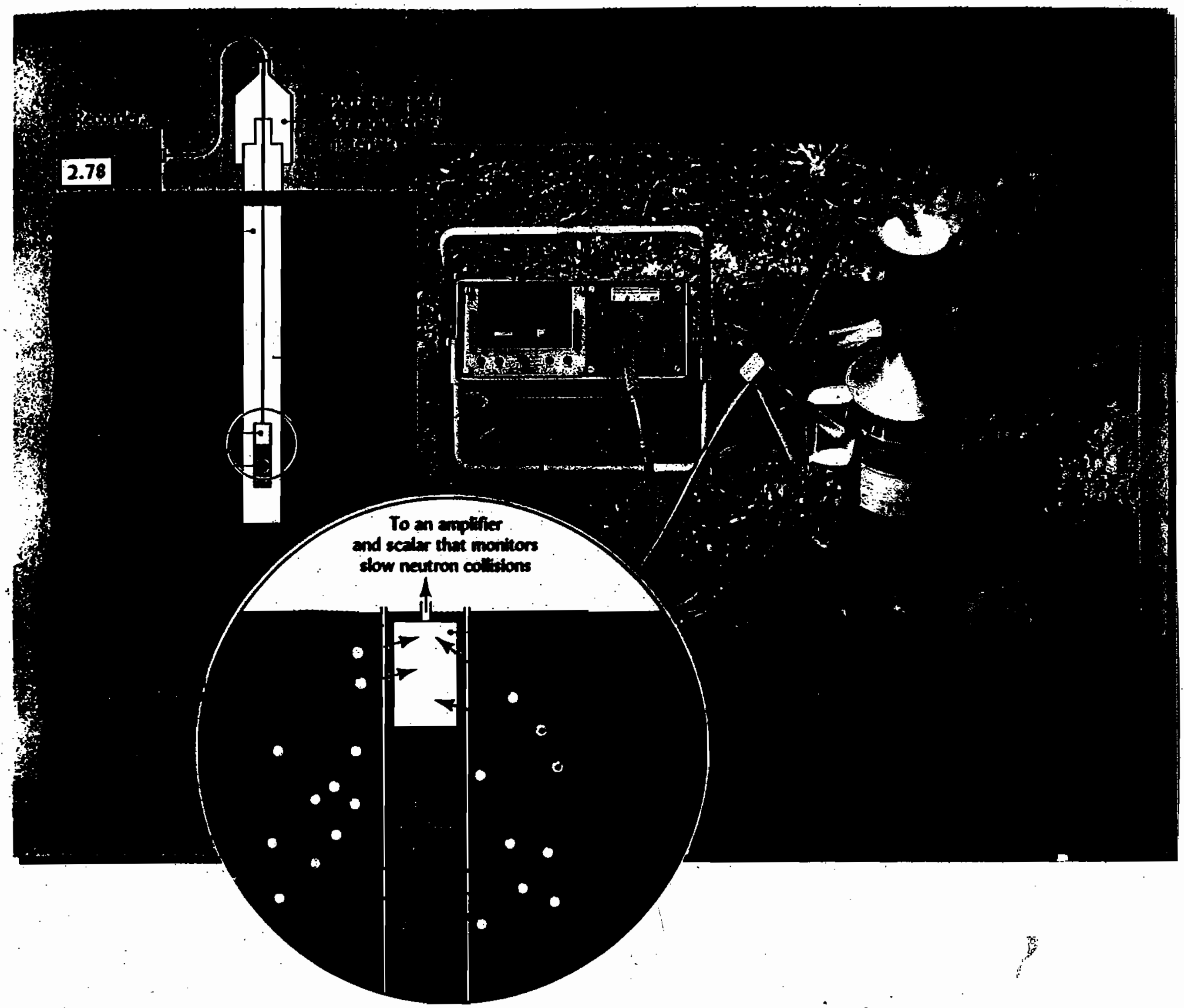


FIGURE 5.15 How a neutron moisture meter operates. The probe, containing a source of fast neutrons and a slow neutron detector, is lowered into the soil through an access tube. Neutrons are emitted by the source (e.g., radium or americium-beryllium) at a very high speed (fast neutrons). When these neutrons collide with a small atom, such as the hydrogen contained in soil water, their direction of movement is changed and they lose part of their energy. These slowed neutrons are measured by a detector tube and a scalar. The reading is related to the soil moisture content. The photograph shows a neutron probe in the field. The heavy metal cylinder is a shield to protect the operator from irradiation. It will be placed over the aluminum-lined hole (extreme lower right) and the neutron source will then be lowered down into the hole for measurement. (Photo courtesy of R. Weil)

VADOSE ZONE HYDROLOGY
(Stephens, 1997)

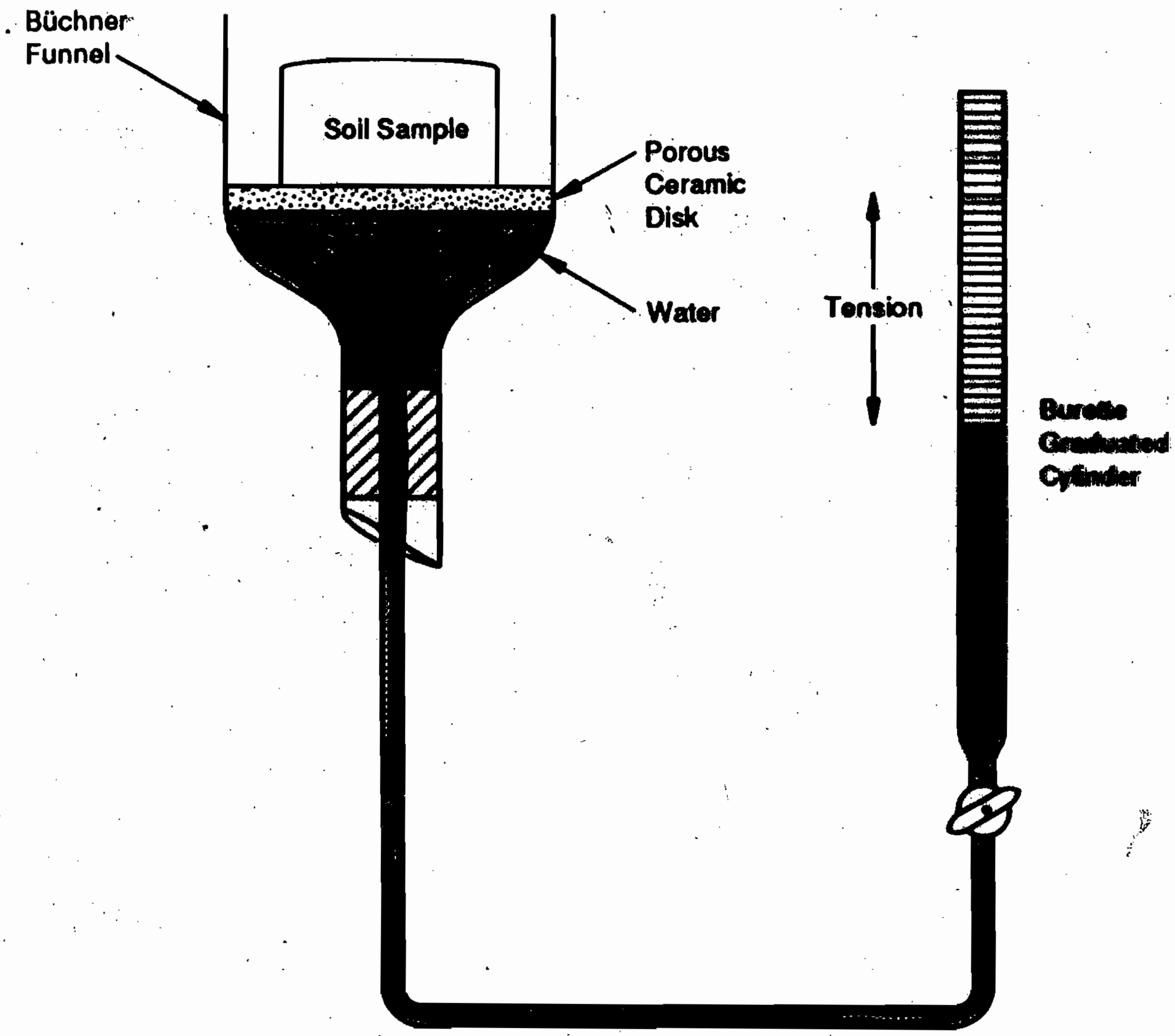


Figure 32 Hanging water column (Büchner funnel) apparatus.

For measuring water content versus pressure head in Soil

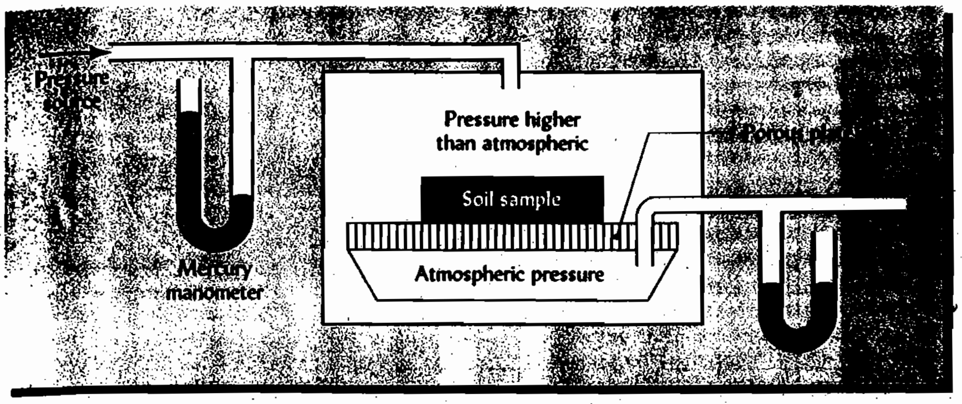


FIGURE 5.18 Pressure membrane apparatus used to determine water content–matric potential relations in soils. An outside source of gas creates a pressure inside the cell. Water is forced out of the soil through a porous plate into a cell at atmospheric pressure. The applied pressure when the downward flow ceases gives a measure of the water potential in the soil. This apparatus will measure much lower soil water potential values (drier soils) than will tensiometers or tension plates.

Saturated flow

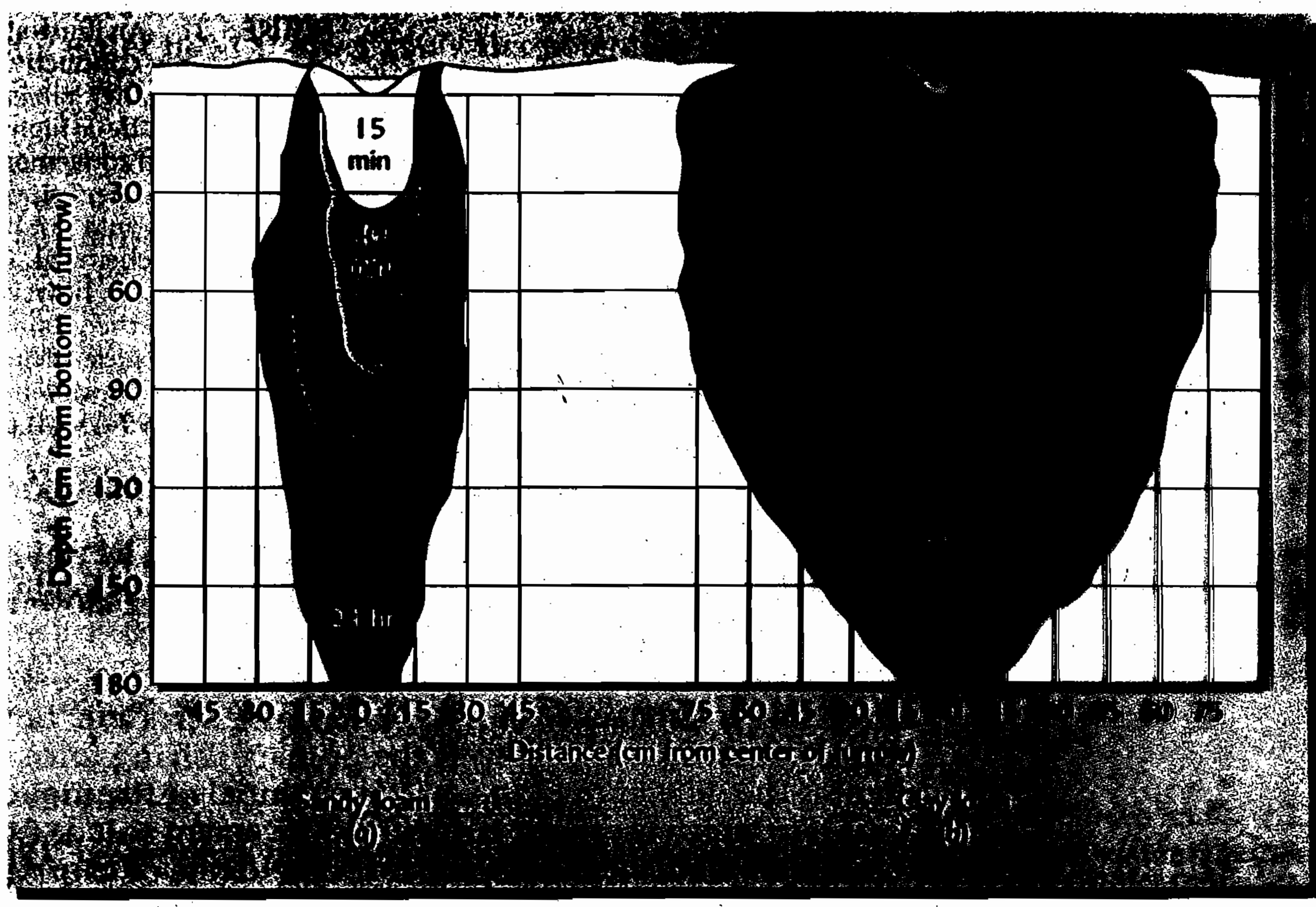
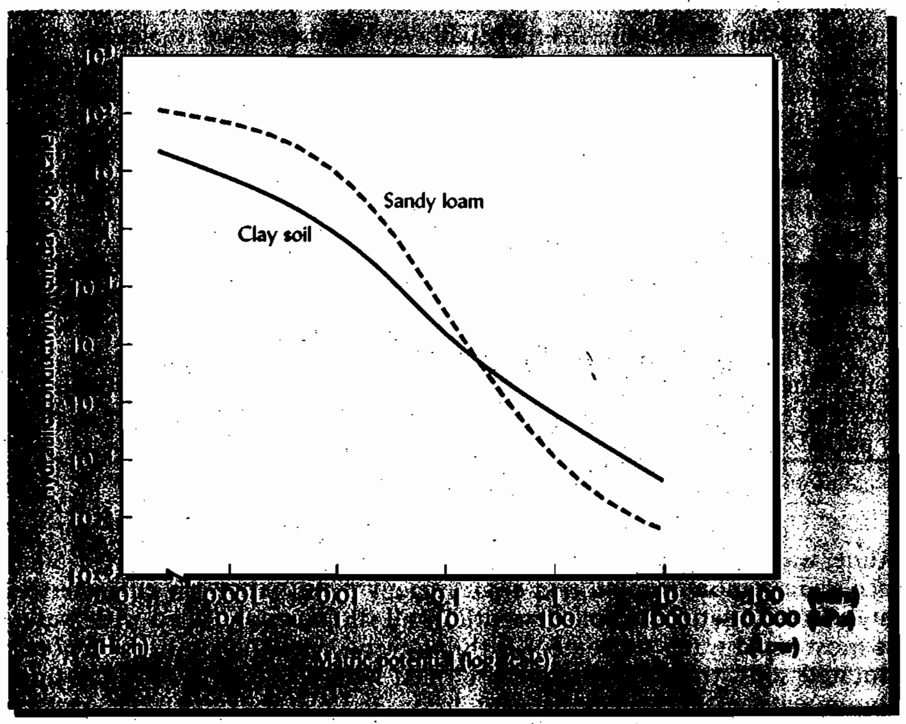


FIGURE 5.20 Comparative rates of irrigation water movement into a sandy loam and a clay loam. Note the much more rapid rate of movement in the sandy loam, especially in a downward direction. [Redrawn from Cooney and Peterson (1955)]

$$K_{sat} = \frac{Q}{At} \cdot \frac{L}{\psi_1 - \psi_2}$$

Textural influences on
Unsaturated flow vs. Saturated flow

K



ψ

FIGURE 5.22 Generalized relationship between matric potential and hydraulic conductivity for a sandy soil and a clay soil (note log scales). Saturation flow takes place at or near zero potential, while much of the unsaturated flow occurs at a potential of −0.1 bar (−10 kPa) or below.

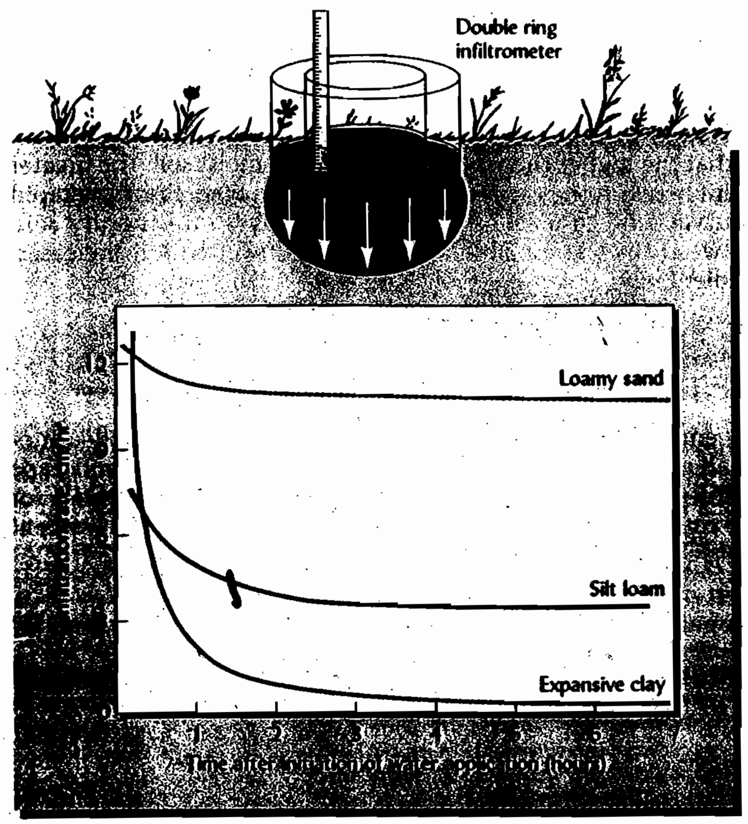


FIGURE 5.24 The potential rate of water entry into the soil, or infiltration capacity, can be measured by recording the drop in water level in a double ring infiltrometer (top). Changes in the infiltration rate of several soils during a period of water application by rainfall or irrigation are shown (bottom). Generally, water enters a dry soil rapidly at first, but its infiltration rate slows as the soil becomes saturated. The decline is least for very sandy soils with macropores that do not depend on stable structure or clay shrinkage. In contrast, a soil high in expansive clays may have a very high initial infiltration rate when large cracks are open, but a very low infiltration rate once the clays swell with water and close the cracks. Most soils fall between these extremes, exhibiting a pattern similar to that shown for the silt loam soil.

$$i = \frac{Q}{A \cdot t}$$

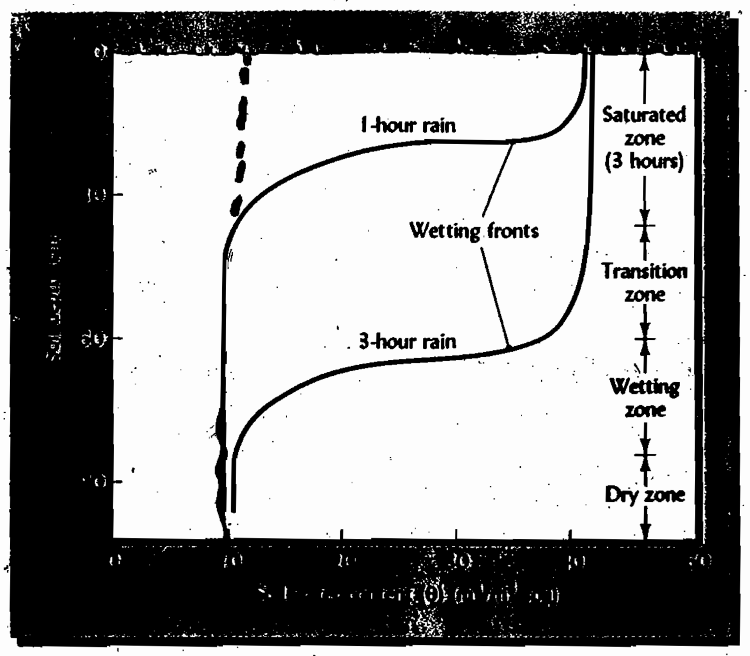


FIGURE 5.26 Water infiltration into a relatively dry soil after one and three hours of a steady rain. The wetting fronts indicate the depth of water penetration. After three hours, the upper 30 to 40 cm of soil is saturated with water. There is a transition zone of near saturation with water above the wetting zone which, in turn, is above the dry zone.

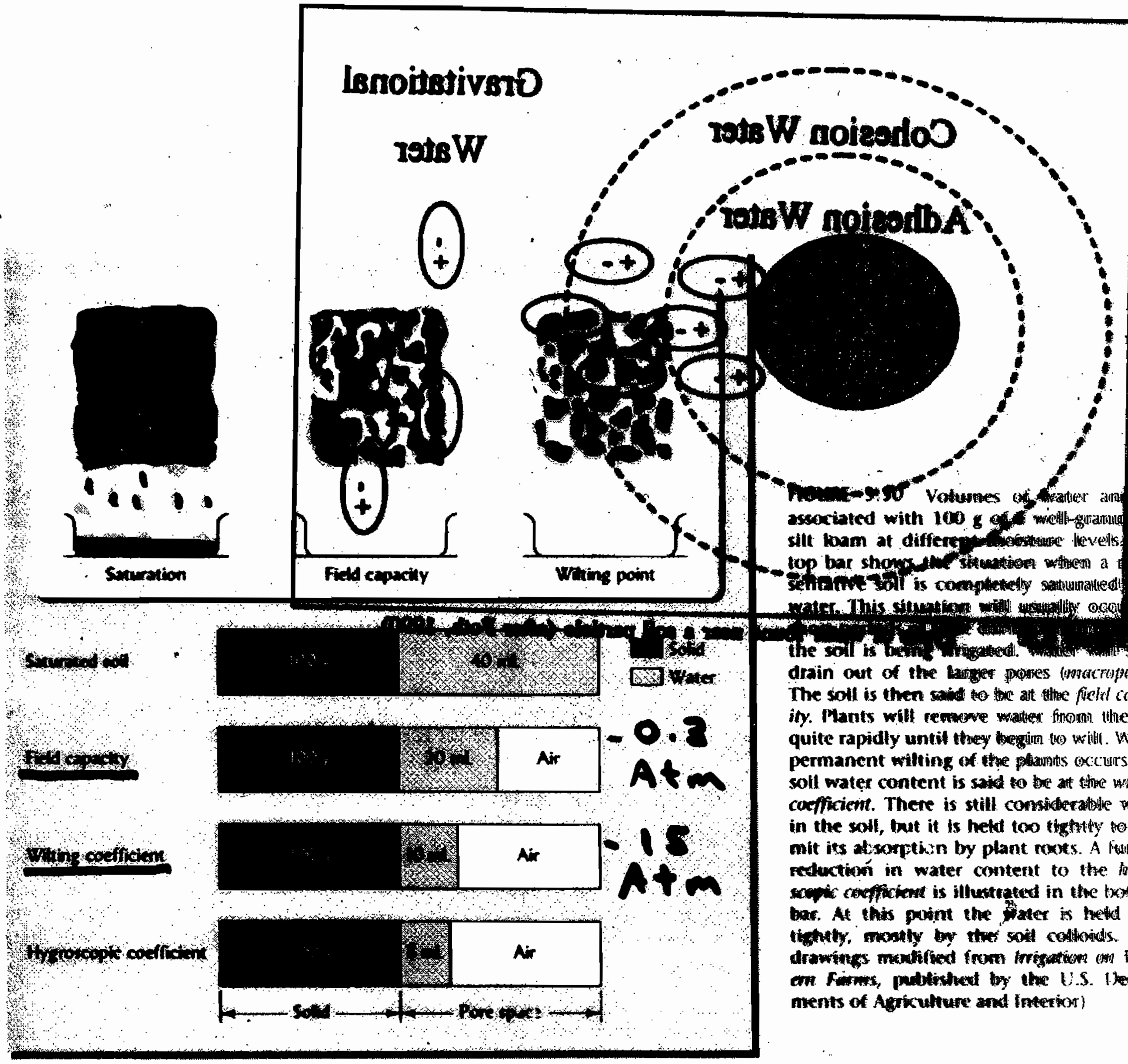


FIGURE 5.10 Volumes of water and air associated with 100 g of a well-granulated silt loam at different moisture levels. The top bar shows the situation when a representative soil is completely saturated with water. This situation will usually occur for short periods of time during a rain or when the soil is being irrigated. Water will soon drain out of the larger pores (*macropores*). The soil is then said to be at the *field capacity*. Plants will remove water from the soil quite rapidly until they begin to wilt. When permanent wilting of the plants occurs, the soil water content is said to be at the *wilting coefficient*. There is still considerable water in the soil, but it is held too tightly to permit its absorption by plant roots. A further reduction in water content to the *hygroscopic coefficient* is illustrated in the bottom bar. At this point the water is held very tightly, mostly by the soil colloids. (Top drawings modified from *Irrigation on Western Farms*, published by the U.S. Departments of Agriculture and Interior)

exact proportions depend on texture and structure

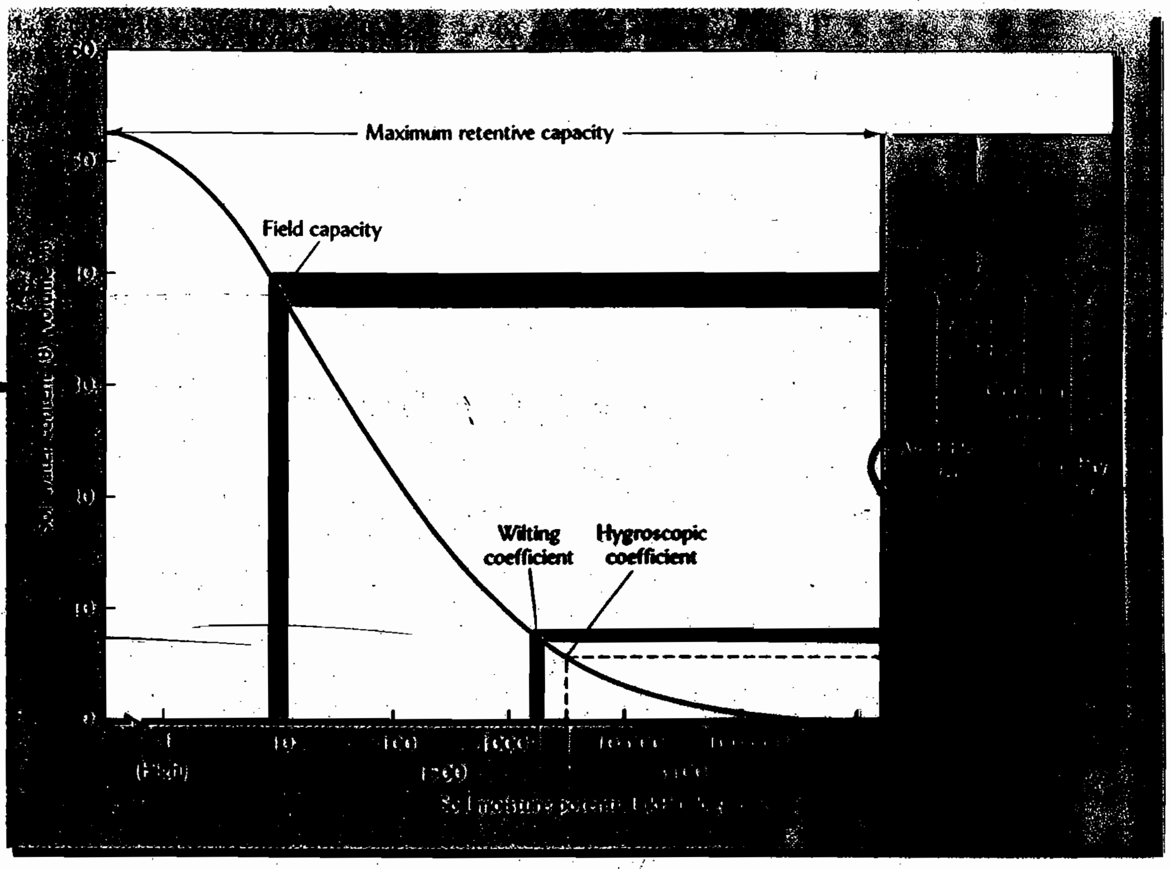


FIGURE 5.32 Water content–matric potential curve of a loam soil as related to different terms used to describe water in soils. The wavy lines in the diagram to the right suggest that measurements such as field capacity are only approximations. The gradual change in potential with soil moisture change discourages the concept of different "forms" of water in soils. At the same time, such terms as *gravitational* and *available* assist in the qualitative description of moisture utilization in soils.

θ

ψ

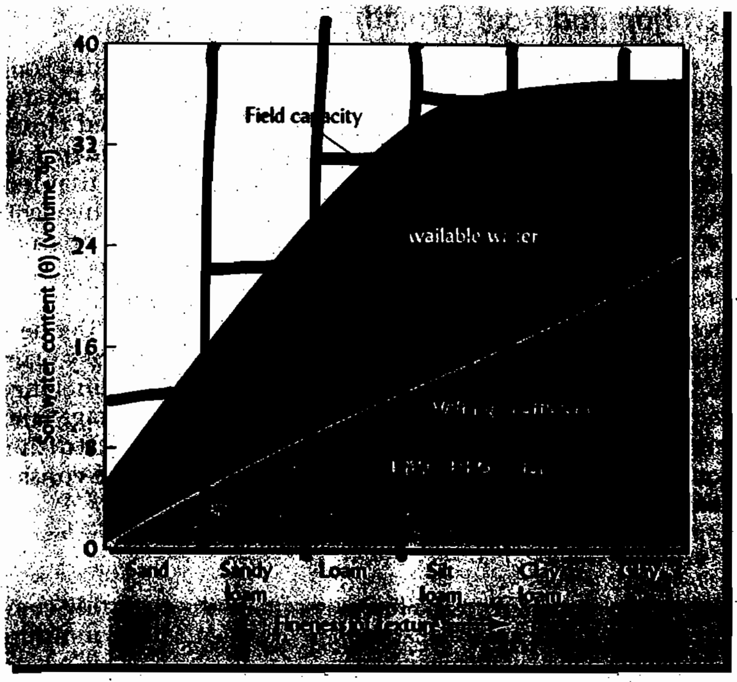
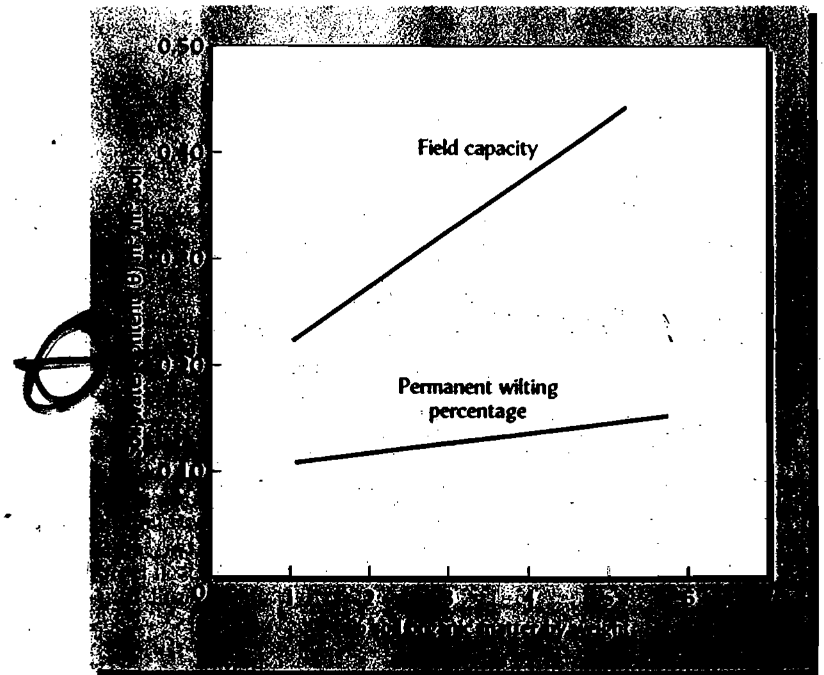


FIGURE 5.33. General relationship between soil water characteristics and soil texture. Note that the wilting coefficient increases as the texture becomes finer. The field capacity increases until we reach the silt loams, then levels off. Remember these are representative curves; individual soils would probably have values different from those shown.



% O.M.

FIGURE 5.34 The effects of organic matter content on the field capacity and permanent wilting percentage of a number of silt loam soils. The differences between the two lines shown is the available soil moisture content, which was obviously greater in the soils with higher organic matter levels. [Redrawn from Hudson (1994); used with permission of the Soil & Water Conservation Society]

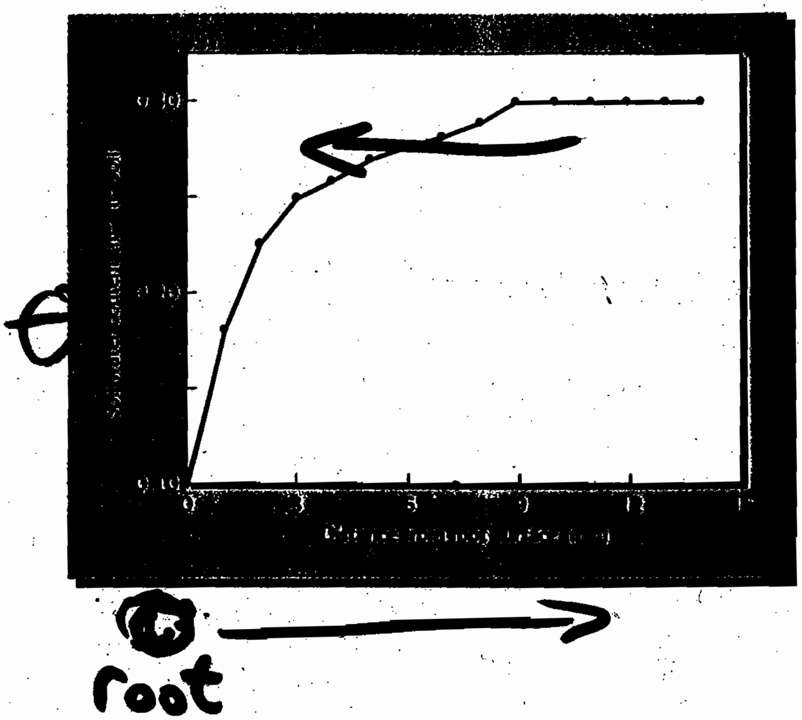


FIGURE 5.36 The drawdown of soil water levels surrounding a radish root after only two hours of transpiration. Water has moved by capillarity from a distance of at least 9 mm from the surface of the root. [Modified from Hamza and Aylmore (1992); used with permission of Kluwer Academic Publishers, The Netherlands]

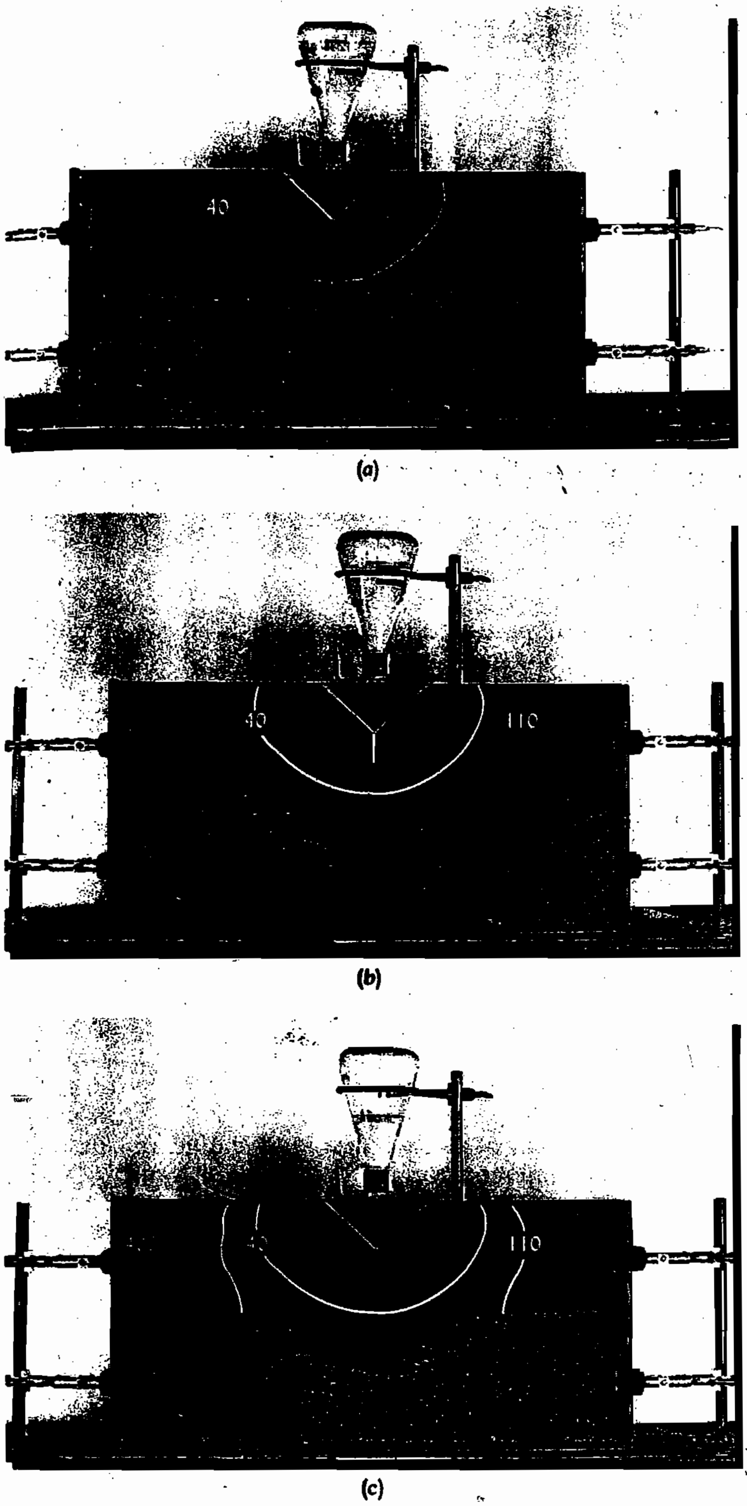


FIGURE 5.27 Downward water movement in soils with a stratified layer of coarse material. (*a*) Water is applied to the surface of a medium-textured topsoil. Note that after 40 min, downward movement is no greater than movement to the sides, indicating that in this case the gravitational force is insignificant compared to the matric potential gradient between dry and wet soil. (*b*) The *downward* movement stops when a coarse-textured layer is encountered. After 110 min, no movement into the sandy layer has occurred. The macropores of the sand provide less attraction for water than the finer-textured soil above. Only when the water content (and in turn the matric potential gradient) is raised sufficiently will the water move into the sand. (*c*) After 400 min, the water content of the overlying layer becomes sufficiently high to give a water potential of about −1 kPa or more, and downward movement into the coarse material takes place. (Courtesy W. H. Gardner, Washington State University)