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Soil and Water

Physical Principles and Processes

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*Dedicated to the memory of
my father, whose silent
presence has guided my effort.*

6 *Infiltration—Entry of Water into Soil*

A. General

Infiltration is the term applied to the process of water entry into the soil, generally (but not necessarily[1]) through the soil surface and vertically downward. This process is of great practical importance, since its rate often determines the amount of runoff which will form over the soil surface (and hence also determines the hazard of erosion) during rainstorms. Where the rate of infiltration is limiting, the entire water economy of the rooting zone of plants may be affected. Knowledge of the infiltration process as it relates to soil properties and mode of water supply is needed for efficient soil and water management. Comprehensive reviews of infiltration processes were published by Parr and Bertrand (1960) and by Philip (1969).

B. Description of the Process

If we sprinkle or otherwise supply water to the soil surface at a steadily increasing rate, sooner or later the moment will come when the supply rate begins to exceed the capability of the soil to absorb water, and the excess will accumulate and pond over the surface, or trickle downslope as runoff (Fig. 6.1). The *infiltration rate* is the flux passing through the surface and

[1] Water may enter the soil through the entire surface uniformly, as under ponding or rain; or it may enter the soil through furrows or crevices, or it may move up into the soil from a source below (e.g., a high water table).

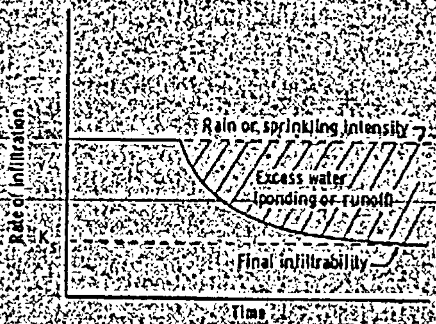

Fig. 6.1. Dependence of the infiltration rate upon time, under an irrigation of constant intensity lower than the initial value, but higher than the final value of soil infiltrability.

flowing into the profile. The *infiltration capacity*,[2] which we propose to call *soil infiltrability*, is the flux which the soil profile can absorb through its surface when it is maintained in contact with water at atmospheric pressure. As long as the rate of water supply to the surface is smaller than soil infiltrability, water infiltrates as fast as it is supplied and the supply rate determines the infiltration rate (i.e., the process is *flux-controlled*). However, once the supply rate exceeds soil infiltrability, it is the latter which determines the actual infiltration rate, and thus the process becomes *profile-controlled*.

If a shallow layer of water is instantaneously applied, and thereafter maintained, over the surface of an initially unsaturated soil, the full measure of soil infiltrability comes into play from the start. Many measurements of infiltration under shallow ponding have shown infiltrability to vary, and generally to decrease, in time. Thus, the *cumulative infiltration*, being the time integral of the infiltration rate, has a curvilinear time dependence, with a gradually decreasing slope.

Soil infiltrability and its variation with time are known to depend upon the initial wetness and suction, as well as on the texture, structure, and uniformity (or layering sequence) of the profile. In general, soil infiltrability is high in the early stages of infiltration, particularly where the soil is initially quite dry, but tends to decrease monotonically and eventually to approach asymptotically a constant rate which is often termed the *final infiltration capacity*[3] but which we prefer to call the *steady-state infiltrability*.

[2] The word "capacity" is generally used to denote an amount, or a volume. Its use in connection with the time-rate of a process can be misleading.

[3] The adjective "final" in this context does not signify the end of the process (since infiltration can persist practically indefinitely if profile conditions permit) but it does indicate that soil infiltrability has finally attained a constant value from which it appears to decrease no more.

Numerous empirical expressions have been proposed to describe the dependence of infiltrability upon time and upon cumulative infiltration. Among these are the equations of Kostiakov (1932) and of Horton (1940). However, purely empirical equations, not based on basic physical relationships, cannot be expected to apply universally.

The decrease of infiltrability from an initially high rate can in some cases result (at least in part) from gradual deterioration of soil structure and the consequent partial sealing of the profile by the formation of a dense surface crust, or from the detachment and migration of pore-blocking particles, or from swelling of clay, or from entrapment of air bubbles or the bulk compression of soil air if it is prevented from escaping as it is displaced by incoming water. Primarily, however, the decrease in infiltration rate results from the inevitable decrease in the matric suction gradient (constituting one of the forces drawing water into the soil) which occurs as infiltration proceeds.

If the surface of an initially dry soil is suddenly saturated, the matric suction gradient acting in the surface layer is at first very steep. As the wetted zone deepens, however, this gradient is reduced, and, as the wetted part of the profile becomes thicker and thicker, the suction gradient tends eventually to become vanishingly small. In a horizontal column, the infiltration rate eventually tends to zero, whereas in downward flow into a vertical column, the infiltration rate can be expected to settle down to a steady rate, gravity-induced, which, as we shall later show, is practically equal to the saturated hydraulic conductivity if the profile is homogeneous and structurally stable. If the surface is supplied with water at a rate lower than the saturated conductivity, or is otherwise maintained at a wetness lower than saturation, then the steady infiltration rate will correspond to the unsaturated conductivity at the particular wetness obtained.

C. Profile Moisture Distribution during Infiltration

If we examine a homogeneous profile at any moment during infiltration under ponding, we shall find that the surface of the soil is saturated, perhaps to a depth of several millimeters or centimeters, and that beneath this zone of complete saturation is a lengthening zone of apparently uniform, nearly saturated, wetness, known as the *transmission zone*. Beyond this zone there is a *wetting zone*, in which soil wetness decreases with depth at a steepening gradient down to a *wetting front*, where the moisture gradient is so steep[4]

[4] The reason for the steepening gradient is that, as the water content decreases, the hydraulic conductivity generally decreases exponentially. Since the flux is the product of the gradient by the conductivity, it follows that, to get a certain flux moving in the soil, the gradient must increase as the conductivity decreases.