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Study of infiltration process under different experimental conditions

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ABSTRACT

In the present study, an attempt was made to evaluate the effect of head of ponding, diameter of ring infiltrometer and depth of penetration on cumulative infiltration. The effectiveness of a double ring infiltrometer on reducing lateral flow was also studied. The observations on cumulative infiltration were taken for different cases, viz., (i) single ring infiltrometers of 0.1, 0.15, 0.2, 0.25 and 0.3 m diameters and 0.06, 0.13, 0.16, 0.2, 0.26 m head of ponding with 0.07 m depth of penetration, (ii) 0.1 m diameter single ring infiltrometer with 0.3 m depth of penetration and (iii) double ring infiltrometers with 0.1–0.35 and 0.35–0.6 m set combination with 0.07 m depth of penetration. The study was conducted in G1 block of Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pant Nagar, India. The infiltration data obtained for different combinations were used to study the effect of the parameters on wetting front advance and observed that the length of wetting zone at the central axis of the infiltrometer increases with increasing diameter of infiltrometer and head of ponding. Vertical and lateral components of cumulative infiltration were estimated from the moisture stored in the soil during the infiltration process. The lateral component ranged from 31.8 to 67.9% for the case of single ring infiltrometers and 11.7–11.92% for the case of double ring infiltrometer with 0.07 m depth of penetration. It shows that the lateral component of infiltration is reduced by three to six times with double ring infiltrometer. The excess amount of lateral component estimated with single or double ring infiltrometer is to be taken into account while designing an irrigation system. Further, a dimensionless equation was developed to predict the cumulative infiltration and the results are found very close to the observed data.

1. Introduction

Infiltration characteristics of the soil constitute one of the basic and most important parameters for proper design and management of field irrigation systems. Infiltration is a complex physical process, which is difficult to characterize accurately for the isotropic and heterogeneous conditions commonly found in irrigated lands. It also varies during the crop season due to various factors such as soil compaction, moisture regime, etc. The precise measurement of infiltration of water into the soil not only helps in optimizing the water resources but also minimizes soil erosion. Further, the volume of irrigation water that infiltrates through soil, effects the amount of runoff and deep percolation and the uniformity and efficiency of the entire

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system. Field water infiltration or intake rate at the soil surface is often measured using ring infiltrometers (Bouwer, 1986; Reynolds et al., 2002). Wu et al. (1999) automated the infiltration measurement with the help of pressure transducers using single ring infiltrometers. However, the total flow rate into the soil from a single ring infiltrometer is a combination of both vertical and horizontal flow (Tricker, 1978). Reynolds and Elrick (1990) considered the infiltration process of a single ring as a three-dimensional (3-D) problem. The lateral flow increases the infiltration rates and the basic infiltration rates (the constant infiltration rate that attains during the infiltration process after some time has elapsed) are quickly approached. Some times the basic infiltration rate may reach the value, which is larger than the infiltration capacity of the soil. Bagarello and Sgroi (2004) studied the temporal changes of saturated hydraulic conductivity in surface field soil using single ring infiltrometer. He suggested that the large diameter ring should be used as it is more effective in reducing both edge effects and disturbance of the sampled soil volume.

Youngs (1987) conducted experiments for measuring infiltration from ring infiltrometers of radii 0.455, 0.304, 0.152, 0.091, 0.049, 0.024 and 0.01 m. He concluded that the results were consistent from site to site when the ring size was at least 0.15 m. In order to lessen the lateral flow, double ring infiltrometers are being used extensively where a buffer ring is used to lessen the lateral movement from the inner ring, on which the measurements are made. However, the effectiveness of this arrangement cannot be judged accurately. Burgy and Luthin (1956) reported that there is no significant difference in the results of infiltration measured by single ring infiltrometers of 0.15 m diameter and double ring infiltrometers (0.15 m inner ring 0.3 m outer ring). Swartzendruber and Olsen (1961) reported that the most satisfactory concentric ring size throughout all the various conditions studied in a sand model was 0.6 m of outer ring radius and 0.5 m of inner ring radius. Ahuja (1976) reported that from an inner ring of 0.3 m diameter, the lateral flow was practically eliminated when a buffer ring of 0.9 m diameter was employed. Further, he reported that its effect on final infiltration rate was negligible even when a buffer ring of 0.6 m diameter was used. However, difference in water levels between the inner ring and buffer ring effect the infiltration rates measured in the inner ring (Bouwer, 1963). The effect of ring infiltrometer diameter on infiltration rate was also studied by Marshal and Stirk (1950), Aronovici (1955), Youngs (1987). They reported that the unbuffered velocity decreased asymptotically as the ring size increases.

Further, the rate of change of infiltration rate depends on the depth of surface or ponding water (Schiff, 1953; Parlange and Hill, 1976; Reeder, 1980). Philip (1958) reported that for small values of the water depth (H), increasing H increases the infiltration rate and the cumulative infiltration by about 2%/cm of H. The effect of head of ponding on infiltration will be relatively more profound in wet than dry soils. Since wet soils have high initial water content, the effect of water pressure is more and the infiltration rate is less. Initial water content is the major or dominant factor to determine infiltration rate in first few hours of an experiment. As the time increases, the dependence of initial moisture content becomes less important (Tisdal, 1951; Philip, 1957; Fernandez and Wilkinson, 1965). The infiltration process can be understood more logically by monitoring the profile of wetting front advance. Nielsen (1961) estimated the theoretical moisture profile from numerical analysis of a differential equation. According to Philip (1958), the shape of wetting front depends upon the relative importance of matric and gravitational forces during infiltration. Angulo-Jaramillo et al. (2000, 2003) studied the influence of the gravitational force and head of ponding on the infiltration process. If the matric forces predominate, the wetting front is almost spherical. If gravity is predominant, as in case of coarse textured soils, then the wetting front is elongated and more nearly ellipsoidal in shape. Jafri (1971) studied the moisture front and reported that the wetting front had a parabolic shape and the drying pattern changed with time. Parlange and Hill (1976) reported that the wetting front moving in a homogeneous soil at sufficiently low speed is unstable. The profile of moisture front advance is a function of time and closely approximated to a semi-elliptical shape (Kaul, 1979). The wetted zone is displaced toward the region of lower moisture tension. This is due to the higher rate of water flow towards this region and specially to the higher soil water permeability. Lateral flow decreased with time during infiltration. Under the moist to wet conditions of the soil, lateral flow was not appreciable (Ahuja, 1976). Large variations in hydraulic conductivity values were found from experiments with small sized rings, but little variations were found for large sized rings (Youngs, 1987).

Thus, the accuracy of infiltration data not only depends on the method by which infiltration test is conducted but also depends on various parameters such as head of ponding, ring diameter, initial soil moisture content and saturated hydraulic conductivity. Liu et al. (2001) estimated the extent of infiltration in a paddy field by adopting a one-dimensional Darcy-based soil and water balance model and two sets of empirical equations (Chen and Lee, 1964). Their findings suggested that the empirical equations designed to estimate the amount of irrigation water required for rice growth in the paddy may over estimate infiltration rates. Reynolds and Elrick (1990) developed a solution for steady state water flow rate from a single ring infiltrometer using hydraulic function and a shape factor accounting for various radii and insertion depth. Wu and Pan (1997) developed a generalized infiltration curve for single ring infiltrometers by modifying the Reynolds and Elrick method to accommodate the popular Van Genuchten (1980) hydraulic functions. Wu et al. (1997) studied the infiltration rate for a single ring infiltrometer using a scaling technique involving saturated hydraulic conductivity, ring insertion depth, ponding depth and ring diameter. Understanding the effect of these parameters on cumulative infiltration may provide more accurate data, which is a primary data source in estimating the water intake capacity of soil and evaluation of mathematical models.

Hence, the present study was taken up to evaluate the effect of major parameters such as cylinder diameter, head of ponding and depth of penetration on single ring infiltration. The effectiveness of double ring infiltrometers of different combinations in reducing lateral flow was also studied. The infiltration data obtained for different combinations were used to study the effect of the parameters on cumulative infiltration, wetting front advance and vertical and lateral infiltration. Further, a relationship was developed to quantify cumulative infiltration using dimensional analysis technique.