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Using the Recycling Infiltrometer to Evaluate the Infiltration Characteristics of Three Furrow Shapes at the Greenville Farm in Logan, Utah (Usa).

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ABSTRACT: *A recycling furrow infiltrometer was used to measure the intake (infiltration rate) characteristics of three furrow shapes, a triangular (V)-shaped, trapezoidal-shaped and a rectangular-shaped. The soils were predominately a Millville silt loam soil. The infiltration rate from the triangular shaped furrow was lower (slower) than from a trapezoidal-shaped furrow, which was also lower than a rectangular shaped furrow. More water infiltrated a rectangular shaped furrow per unit time than in either the trapezoidal-shaped furrow or triangular-shaped furrow. Natural settling of soil behind the furrow forming implement possibly affected the hydraulics of the furrows. The equation derived for the infiltration function was of a power function with R^2 values more that 0.98 (R^2 > 0.98). For long opportunity time, the shape of the furrow appeared not to affect the basic infiltration rate.*

KEY WORDS: *Recycling infiltrometer, basic infiltration rate, furrow shapes, irrigation.*

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I. INTRODUCTION

Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile. The soil temporarily stores water, making the water available for root uptake, plant growth and as habitat for soil organisms. Furrow infiltration increases with wetted perimeter and this effect strongly influence water distribution along furrows (Trout, 1992). Wetted perimeter and flow velocity vary across a furrow irrigated field and may influence the infiltration. If however, their effects are known, the influence of the flow rate, slope and roughness on infiltration can be predicted (Dlamini, 2001).

Soil infiltration characteristics are important for the evaluation, design and management of surface irrigation systems (Dedrick et al., 1985; Silahou et al., 2020; Walker, 2003). Irrigation cannot be practiced without the knowledge of the soil infiltration rate. Knowledge of the basic infiltration rate is needed when selecting a method of irrigation (Hargreaves and Merkely, 2004). Infiltration rates are also useful for estimating the amount of effective rainfall in hydrology studies. While there are standard values available for different soil types, land cover also has a documented influence on infiltration rates. This makes infiltration highly variable across spatiotemporal scales and as such, difficult to measure in field, thus selection of an appropriate measurement technique is important to consider (Söderberg, 2015).

Measurement of infiltration rates is difficult (Akhavan and Mahdavi, 2015) because of the soil heterogeneity and soil spatial variability influence on the measurements. With the adoption of empirical infiltration models, the ability to describe the distribution of water

in the subsurface is lost (Furman et al., 2006). Soils infiltration rates can be measured using cylinder ring infiltrometers (Rodríguez-Juárez et al., 2018; Salahou et al., 2020), ponds, inflow-outflow furrows, blocked (ponded) furrows, and through the use of special equipment such as recycling (flowing) furrow infiltrometers (Walker and Willardson, 1983; Walker and Skogerboe, 1987).

A recycling furrow infiltrometer is an instrumentation package that runs water through a short section of furrow and measures the infiltration rate of the soil as a function of time (Dedrick et al., 1985; Walker and Skogerboe, 1987; Trout, 1991; Dlamini, 2001). The recycling infiltrometer assembly consists of a small reservoir with a water level recorder. Water is pumped at a fixed discharge rate to the inlets of furrow test sections. As water flows through the test sections, it is pumped back into the reservoir. The procedure is carried out to determine the cumulative infiltration (I) as a time distribution of volumetric depletion in the reservoir. With time, a steady infiltration (f_0) is achieved. The analysis uses the Kostiakov-Lewis equation (Dlamini, 2020):

$$I = k\,T^{a} + f_o\,T \qquad (1)$$

where I = cumulative intake(vol./unit width),
t = intake opportunity time,
f_0 = basic intake rate (vol./unit width/unit length or time/unit time),
a and k are empirical constants.

It has the advantage of taking into account both the furrow geometry and the movement of the water along the furrow. It is generally recognized that infiltration measurements taken with flowing water more nearly duplicate the hydraulic phenomena occurring in the furrow during irrigation than methods that use static water (Dedrick et al., 1985). Porous media flow theory (Samani, 1983; Fangmeier and Ramsey, 1978) dictates that, for most conditions, two-dimensional infiltration from furrows should increase with wetted perimeter (P). Infiltration from furrows in homogeneous soils (without interference from neighbouring furrows) should increase with P at a decreasing rate (negative second derivative) as the infiltration geometry converts from that of two dimensional flow from a line source to predominately one dimensional flow. As furrow width increases and lateral flow at the edges becomes relatively less important, the relationship becomes linear.

A number of mathematical models have been developed to simulate the movement of water along furrows (Walker and Humphreys, 1983; Schmitz and Seus, 1992; Valiantzas, 1997; Strelkoff and Katapodes, 1977; Walker and Busman, 1990). These models simulate the depth of flow, advance, recession, infiltrated volume, runoff, and deep percolation volume. It should be understood that the hydraulics of surface irrigation has all the complexities of the unsteady open channel flow plus the added major complication of a variable intake (Tabuada et al., 1995; Or and Walker, 1996). Direct solution of this complex problem is not possible, making all surface irrigation models to be based on the principle of continuity and the conservation of mass.

This paper reports on a study to measure the soil's infiltration rate in three furrow shapes (trapezoidal, rectangular and v-shaped) using the recycling infiltrometer method. Details on the apparatus can be found in Dlamini (2001).

II. MATERIALS AND METHODS

Experimental area

The research was carried out at the Utah State University Greenville farm (Logan, UT: Latitude 41°46′ N, longitude 111°48′ W, and elevation of 1405 m absl) during the summer of 2000. The site is located at 1800 North, 800 East. Six different furrow configurations (Fig 1) each measured 180 m long, 0.45 m wide (top width), and about 0.15 m deep. Where a combination of furrow shapes was used, each was 60 m long. The soils were predominately a Millville silt loam soil.

The Millville series consist of well-drained and moderately well drained very strongly calcareous soils. These soils are formed in alluvium derived from dolomitic limestone. They are on alluvium fans deposited on high and medium lake terrances. The top soil (20 cm) is a dark grayish brown silt loam, very dark grayish brown when moist, weak, medium, granular structure, slightly hard, friable, slightly sticky and slightly plastic (United States Department of Agriculture, 1974).

Data collected during the study were used to plot the advance trajectories of each shape / combination of shapes, and to calculate the cumulative infiltration depth, the application efficiency, deep percolation losses, tail water run off losses, and uniformity for each irrigation event. The distribution of infiltrated water along the furrow was estimated from derived mathematical functions describing infiltration and from data on infiltration opportunity times along the furrow based on the Kostiakov-Lewis equation (Dlamini, 2020).

Experimental procedure

A V-shaped implement was used to make the V-shaped (triangular) furrows, and then the same implement was cut (modified) to make trapezoidal-shaped furrows and later more refined to make the rectangular-shaped furrows. In practice, the three shapes could be hydraulically mounted at the back of the tractor and used consecutively. Three furrows each 45 m long were divided into 6 m lengths and used for the recycling infiltrometer measurements. There were three replicates for each shape. The furrows were at a slope of 0.00914.

Recycling Infiltrometer

A recycling infiltrometer (Dedrick et al., 1985; Walker and Skogerboe, 1987; Trout, 1991; Dlamini, 2001) was used to measure the infiltration characteristics of the soil for each furrow shape. The advantage of this method over the infiltration ring is that both the geometric and hydraulic conditions in the field are simulated. Also suspended particles are kept in suspension rather than being filtered at the soil surface during infiltration and forming a more impermeable soil surface layer that could occur under usual conditions of furrow flow. Other researchers (Fangmeier and Ramsey, 1978) observed that equations developed from other methods, such as ponded infiltration test, underestimated infiltration during irrigation.

The details of how a recycling infiltrometer operates were explained in Dlamini (2001). The rate of soil infiltration is measured by the change in water level in the supply reservoir. The water supply to all three furrow shapes was maintained constant at 60 liters per minute.

III. RESULTS AND DISCUSSION

A water balance can be written at anytime after completion of the advance phase along the furrow as;

$$Q_{in} = Q_z + Q_{tw} \quad (2)$$

where, Q_{in} is the discharge rate of the circulating centrifugal pump, m^3/min), Q_z is the discharge rate infiltrating into the soil, m^3/min; and Q_{tw} is the tail water being pumped from the runoff sum back to the tank, m^3/min. The infiltration rate can also be written as (Walker and Skogerboe, 1987);

$$Q_z = A_f \text{ x } I \quad (3)$$

where, A_f is the ground surface area served by the furrow, m^2, and I is the infiltration rate, m/min. Since the rate of fall of the water of the water in the supply reservoir is also a measure of the infiltration rate, Q_z, we can also write the following equation;

$$Q_z = A_r \frac{dh}{dt} \quad (4)$$

where, Ar is the cross-sectional area of the water supply reservoir, m^2, and dh/dt is the rate of depletion of the water level in the supply reservoir, m/min. Equations (3) and (4) can be combined to form the following equation;

$$I = \frac{A_r}{A_f}\frac{dh}{dt} = C\frac{dh}{dt} \quad (5)$$

where C is the ratio of the cross sectional area of the water supply reservoir to the ground surface area served by the furrow. The cumulative infiltration of water in the soil is given by:

$$Z = C\ x\ \Delta h \quad (6)$$

where Δh is the total change in the water level drop in the water supply reservoir. Equations (5) and (6) were used to calculate the infiltration rate and the cumulative infiltration in the soil.

Hydraulic properties of the furrows

The measured hydraulic properties of the three furrow shapes before the beginning of the experiment are summarized in table 1.

There were noticeable similarities between the trapezoidal and rectangular furrows. This is possible due to the possible redistribution of the soil behind the implement during furrow forming. The calculated wetted perimeter for the trapezoidal furrow was higher than both the triangular and rectangular furrows. The triangular shaped furrow had the smallest cross-sectional area.

Table 1. Summary of the measured hydraulic properties of the furrow shapes before water application.

Hydraulic property	Triangular (V)	Trapezoidal (Tp)	Rectangular (R)
Topwidth (T)	0.43	0.45	0.47
Depth (y)	0.12	0.11	0.10
Bottom width (b)	0	0.16	0.20
Side slope (m)	1.79	1.32	1.35

Calculated Properties			
Wetted perimeter (P)	0.492	0.524	0.470
Cross sectional Area (A)	0.0258	0.0336	0.0335
Hydraulic Radius (Rh)	0.0524	0.0641	0.0713

Infiltration rate curves

Figure 1 shows a graph of the infiltration rate with time for the three furrow shapes. It was observed that the infiltration rate was higher for the rectangular shaped furrow and lowest for the triangular shaped furrow throughout the measurement time. However, for longer opportunity time greater than 120 minutes, the graphs tended to approach a common value (the basic infiltration rate).

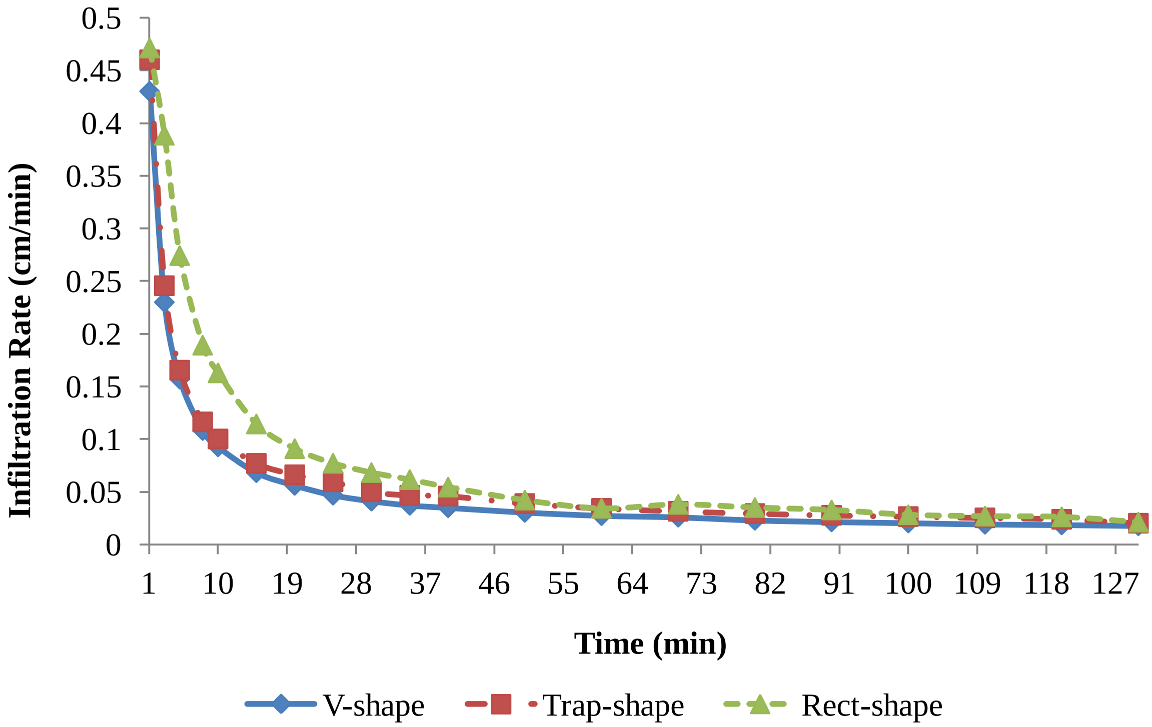

Fig. 1. Infiltration rate curves for the second irrigation event for three furrow shapes at USU Greenville Farm, Logan, during summer.

The trapezoidal and triangular shape furrows showed similar infiltration characteristics. The infiltration rate for the triangular and trapezoidal shape furrows can be represented the equation;

$$Infiltration\ rate\ (I) = 0.72\ X^{-0.699}\ (R^2 = 0.98) \quad (7)$$

And that for the rectangular shaped furrow can be represented by;

$$Infiltration\ rate\ (I) = 0.45\ X^{-0.629}\ (R^2 = 0.997) \quad (8)$$

IV. CONCLUSION

The infiltration rate from the triangular shaped furrow was lower (slower) than from a trapezoidal-shaped furrow, which was also lower than a rectangular shaped furrow. More water infiltrated a rectangular shaped furrow per unit time than in either the trapezoidal-shaped furrow or triangular-shaped furrow. Natural settling of soil behind the furrow forming implement possibly affected the hydraulics of the furrows.

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