# Comparative Study of Irrigation Advance Based Infiltration Methods for Furrow Irrigated Soils

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## ABSTRACT

This study was attempted to evaluate infiltration methods based on irrigation advance for furrow irrigation. Irrigation advance data were collected at Latif farm, Sindh Agriculture University, Tandojam for three irrigation events. To achieve the objectives of the study two different methods viz. Upadhyaya and Raghuwanshi and Valiantzas one-point, were tested against the two-point method. Evaluation of employed methods was undertaken to know the best method for the prediction of cumulative infiltration and advance. The results revealed that Upadhyaya and Raghuwanshi (ME=-5.25) and Valiantzas one-point (ME=-0.99) are unsuitable for silt loam soil with their original constants as these methods show great scatter when compared with reference method and measured data. Thus, it is suggested that these methods must be evaluated before use.

*Keywords:* Infiltration characteristics, furrow irrigation, advance, two-point method, Upadhyaya and Raghuwanshi, Valiantzas one-point, Tandojam

## INTRODUCTION

Limited water resources warrant agriculture water management to achieve sustainable development (Valipour, 2013a). Conservation of usable water requires control of evaporation and rapid runoff from soils irrigated by surface irrigation methods (Valipour, 2016; Valipour,2015). Surface irrigation is an

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ancient form of irrigation that is used worldwide. Low efficiency and low uniformity are the main problems that can be tackled by applying optimal management practices that entail the investigation of interaction of irrigation water and soil. Thus, it can be deduced that the estimation of infiltration function is the main hitch in improving the irrigation performance (Elliott, Walker, & Skogerboe, 1983). Infiltration is the downward flow of water from the surface into soil. It plays a vital role in controlling the transport process and water balance in the soil (Serrano, 1990).

Surface irrigation application efficiency and uniformity are governed by the infiltration parameters. Irrigation phases of advance, recession, run-off and volume of infiltration are greatly influenced by the infiltration. Surface irrigation becomes a complex process due to its variability in time and space (Elliott et al., 1983). The knowledge of infiltration characteristics are essential parameters for design, evaluation and simulation of surface irrigation systems. These characteristics are affected by farm operations such as cultivation and compaction but these are taken as a fixed set of parameters in relation to a single irrigation event.

Infiltration rates on a field are influenced by soil characteristics, which control infiltration parameters (Jensen, Swarner, & Phelan, 1987). A large number of infiltration measurements are required to characterise field condition. The method such as double ring infiltrometer involves static water measurement and fails to represent the dynamic field condition. Two approaches are employed to obtain field representative infiltration functions using irrigation data. One of them requires inflow to adjust with the results of point measurements and the other uses irrigation phases and inflow data to determine the infiltration parameters. Several such methods are available to estimate infiltration (Elliott & Walker, 1982). Of them, the two-point method is used worldwide as a standard method to evaluate other methods (McClymont & Smith, 1996).

Valipour (2013b) evaluated management strategies for increasing irrigation efficiencies and stated that all surface methods are not applicable due to the limited amount of water available. Thus, methods that require relatively less water such as furrow can be optimised for controlling parameters (infiltration). Besides that, a number of other parameters need to be considered for selecting an irrigation system that varies from location to location (Valipour, 2013c). Khatri and Smith (2005) tested various infiltration methods and concluded that none of the tested infiltration methods gave satisfactory results due to several inputs required. Shepard et al. (1993) developed and tested a method to determine parameters of Philip's function. He inferred that the developed method was effective for estimating average infiltration, yet it may under- or over-predict infiltration along the furrow owing to changes in infiltration properties. McClymont and Smith (1996) pointed out the limitation of hydrodynamic models and stated that these methods are data intensive. Ebrahimian and Liaghat (2011) checked the accuracy of hydrodynamic, zero inertia and kinematic wave models and stated that these models are suitable for estimating infiltration in furrows. Majdzadeh et al. (2009) pointed out the inaccuracies in estimating the infiltrated volume using the one-point method. This shows the importance of evaluating these methods as suggested by Khatri and Smith (2005), who highlighted that the methods used to determine infiltration should be evaluated before use.

Although many studies have been conducted to evaluate performance of existing methods for different influencing parameters (e.g. Majdzadeh et al., 2009; Khatri & Smith, 2005), yet

investigation of these methods in terms of different soil textures needs to be conducted. Thus, this study was carried out on a particular soil type to evaluate the performance of two different infiltration methods, namely, the Upadhyaya and Raghuwanshi method and the Valiantzas one-point method.

## METHODOLOGY

This study was carried out at Latif farm, Sindh Agriculture University, Tandojam. The field layout is shown in Figure 1. Data for three irrigation events for 15 furrows were recorded. Data for each furrow included inflow rates, irrigation advance times for different points along the furrow, length of furrow and the flow cross-section area.
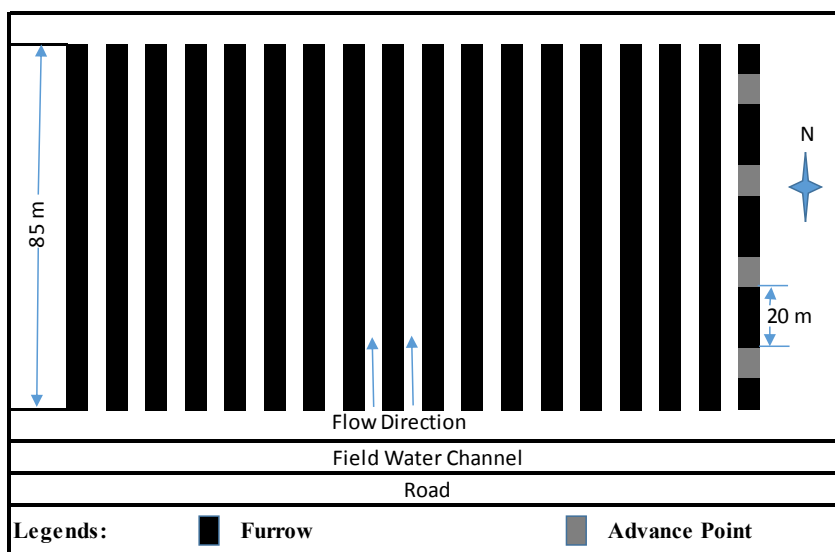


*Figure 1.* Experimental field layout

In order to know soil texture of the field at Latif farm, composite soil samples at the depth 0-15 cm, 15-30 cm and 30-60 cm were collected from various locations. The collected samples were analysed in the laboratory of the Department of Irrigation and Drainage, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam.

A cutthroat flume was used to measure discharge entries in a furrow at the upstream/head of the furrow. To measure the advancing front along the furrows, stakes were placed along the length of the furrow at intervals of 20 m. The ground surface elevation at each stake was surveyed to determine the slope of the irrigated field. The time was recorded as soon as the irrigation supply entered the furrow and the advancing front reached each stake using a stop-watch. Flow depth was measured at several locations with the help of a steel measuring graduated scale.

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The cross-sectional flow area, $A_0$, was computed using the following equation.

$$A_0 = (\frac{b+T}{2})y \tag{1}$$

where, $A_o$, is the cross-sectional area of the flow, $b$ is the bottom width of the furrow, $T$ is the top width of the furrow and y is the depth of flow.

## Methods Used for Computing Infiltration Characteristics

The following methods were tested to compute infiltration characteristics. A brief qualitative and quantitative description of each method is presented in the subsequent paragraphs.

**Two-Point method.** This is a volume-balance-based method. Two points, one at the mid-distance point and the other at the downstream end of the field, are recorded during irrigation advance and used to compute infiltration characteristics. It is a standard method and is used worldwide for determining infiltration characteristics (Khatri & Smith, 2005).

A simple power function is used to estimate advance curve in this method.

$$x = p(t_a)^r \tag{2}$$

where, $t_a$, is the time taken for the wetting front to reach the advance distance, $x$. The fitted parameters, $p$ and $r$, can be evaluated from:

$$r = \frac{\ln(0.5L/L)}{\ln(t_{0.5L}/t_L)} \tag{3}$$

and

$$P = L / t^r \tag{4}$$

where $t_{0.5L}$ and $t_L$ are the times taken for the advance to reach the mid-distance length (0.5L) and the end of the field of length (L).This method uses a modified Kostiakov function, which is expressed as:

$$I = k\tau^a + f_o\tau \tag{5}$$

where $\tau$ is the time from the start of infiltration at the point where the equation is applied. For any point x, $\tau = t - t_x$. For detailed description of this method, readers are referred to the work of Elliott et al. (1983).

**Valiantzas one-point method.** Valiantzas, Aggelides and Sassalou (2001) developed a single-advance-point-based method. They used a USDA equation to determine infiltration function. This method requires only one advance point to estimate the parameters of infiltration function.

$$l = k\tau^{\alpha} + c \tag{6}$$

where $k$ and $\alpha$ are fitted parameters and $c$ is the constant (0.007 m$^3$ m$^{-1}$ length).

In this method, $k$ and $\alpha$ are associated by the following relation.

$$k = \frac{14088\alpha^{45} + 0.148(-\ln\alpha)^{-1.652}}{1000} \tag{7}$$

Substitution of Equation (6) in the volume balance relation and integration yields:

$$Q_o t = \sigma_y A_o x + \sigma_z k t^{\alpha} x + cx \tag{8}$$

where $\sigma_2$ is the sub-surface shape factor.

Using the points $(x_2, t_2)$ and $(x_1, t_1)$ where $t_1 = 0.5 t_2$, we have two simultaneous equations to be solved for the unknown infiltration parameters, viz.:

$$r = [ln\ (x_1/x_2)\ /\ ln\ (t_1/t_2)]$$
$$= [ln\ (0.5 Q_0 t_2)\ /\ (0.5^{\alpha}\ (Q_0 t_2 - \sigma_y A_0 x_2 - cx_2) + \sigma_y A_0 x_2 + cx_2]\ /\ ln\ (1/2) \tag{9}$$

and

$$f(\alpha) = \sigma_z k t_2^{\alpha} - \frac{Q_o t_2 - \sigma_y A_o x_2 - cx_2}{x_2} = 0 \tag{10}$$

The Newton Raphson technique is applied to obtain the value of α, viz.:

$$\alpha_{new} = \alpha - \frac{f(\alpha)}{f^1(\alpha)} \tag{11}$$

where $\quad f^1(\alpha) \approx \sigma_z t_2^{\alpha}\left(\frac{dk}{d\alpha} + k\ln t_2\right) \tag{12}$

Correcting an error in the original paper by Valiantzas et al., (2001), the following is derived:

$$\frac{dk}{d\alpha} = 633.96\alpha^{44} + \frac{0.2445(-\ln\alpha)^{-2.652}}{1000\alpha} \tag{13}$$

Advance trajectories are predicted by the relation.

$$X = Q_o t/\sigma_y A_0 \sigma_z k t^{\alpha} + c \tag{14}$$

**Upadhyaya and Raghuwanshi method.** The Upadhyaya and Raghuwanshi method (1999) employs the exponential Horton equation to describe the infiltration function.

$$l = F(l - e^{-\theta\tau}) + f_o\tau \tag{15}$$

where $F$ and $\theta$ are fitted parameters, and $f_0$ has its usual meaning. The parameter $F$ is the function of the initial and final infiltration rates.

The following relations are used to determine the advance, $\theta$ (exponent in the Horton equation) and xmax (maximum possible advance distance):

$$x = x_{max}(l - e^{-\theta t}) \tag{16}$$

$$\theta = (1/t) * [ln\ (1 - (x/x_{max})] \tag{17}$$

$$(1/t0.5) * [ln\ (1 - (0.5L/xmax)] = (1/t) * [ln\ (1 - (L/x_{max})] \tag{18}$$

The final infiltration rate is computed by the following relation:

$$f_o = \frac{Q_o}{x_{max}} \tag{19}$$

The final volume balance equation is obtained after substituting Equation (15) in the volume balance equation and integration.

$$Q_o = \sigma_y A_o x + Fx - F(x_{max} - x)\theta t + f_o x_{max} t - \frac{f_o x}{\theta} \tag{20}$$

Equation 20 is adjusted to the approximate advance.

## Statistical Criterion

The modelling efficiency (ME) given by Nash and Sutcliffe (1970) was used to describe the accuracy of the models output quantitatively (Zhang et al., 2010). The range of the ME lies between 1.0 (perfect fit) and $-\infty$. An efficiency of lower than zero indicates that the predictor model is not good.

$$Model\ efficiency\ (ME) = 1 - \frac{\sum_{i=1}^{n}(O_i - E_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \tag{21}$$

where $O$ stands for cumulative infiltration computed by the two-point method and $E$ represents the estimated cumulative infiltration achieved using the different methods.

# RESULTS AND DISCUSSION

## Soil Texture, Flow Rate, Advance Time and Depth of Flow

The analysis results on soil texture are shown in Table 1. The results showed that were for a field of silt loam. The recorded flow rates in the furrows and the total advance time are summarised in Table 1. The flow rates ranged from 0.37 to 0.40 $m^3$ $min^{-1}$. The time taken to advance to the strategic location varied from 10 to 14 minutes. The cross-sectional area for the furrow ranged from 0.0226 to 0.0238 $m^2$.

Table 1
*Average flow rate, advance time and textural class*

| S. No. | Flow rate ($m^3$/min) | Total advance time (minutes) | Area of flow ($m^2$) | Soil separate | % | Textural Class |
|--------|------------|------------|------------|------|----|------------|
| 1 | 0.37 | 14.00 | 0.0238 | Sand | 16 | |
| 2 | 0.40 | 10.00 | 0.0226 | Silt | 74 | Silt loam |
| 3 | 0.40 | 10.20 | 0.0233 | Clay | 11 | |

## Computation of Infiltration Characteristics

The estimated functions for cumulative infiltration and advance are tabulated in Table 2. The advance curves and cumulative infiltration curves produced by estimated functions (Table 2) are presented in Figures 2 to 6. The cumulative infiltration was estimated at times equal to the advance time for each method. The curves produced by the tested methods were almost identical. Thus, the average results of each method for 15 furrows are reported in this paper. The performance of each method in the light of results is discussed in the following sections.

Table 2
*Estimated functions of cumulative infiltration and advance*

| Method | Infiltration | Advance |
|--------|-------------|---------|
| Two-point | $I = 0.022 (t)^{0.216}$ | $X = 10.84 (t)^{0.868}$ |
| Valiantzas | $I = 0.0055 (t)^{0.837}+0.007$ | $X = Q0t/ 0.00276A_0t^{0.837}+0.007$ |
| Upadhyaya and Raghuwanshi | $I = 0.1174(1-e^{-0.040t})+0.00166t$ | $X = 1.1t/ 0.09A_0(1+0.04t)-0.040$ |

**Two-Point method.** The two-point method was used as a reference method for this study because of its proven performance over time and over different soils and situations (Khatri & Smith, 2005). The performance of other method is discussed with respect to the two-point method in the subsequent paragraphs. The advance curves reproduced by the two-point method match the measured advance curves well, as shown in Figure 2.
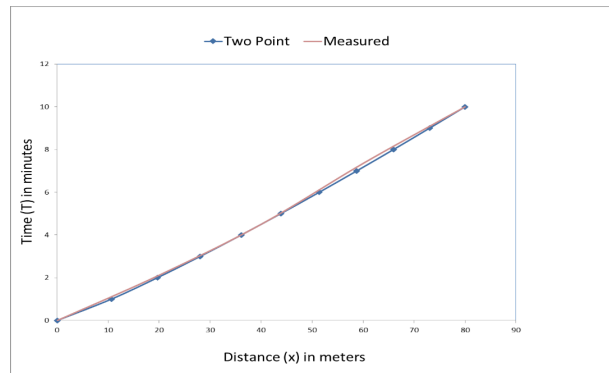
*Figure 2.* Two point method and measured data advance curves

**Valiantzas one-point method.** The advance curves predicted by this method as shown in Figure 3 indicate poor performance of the method as the resulting advance trajectory deviates from the measured advance curve except at the initial and final times. This discrepancy could be due to having used only single advance point in the method.
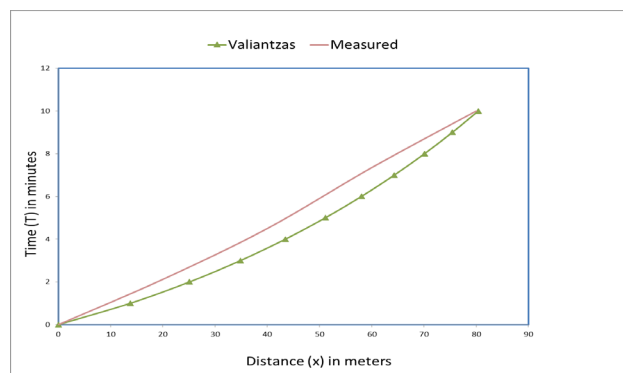


*Figure 3.* Valiantzas method and measured data advance curves

This method underestimated the cumulative infiltration for initial times and overestimated the infiltration for final times (ME=-0.99). The infiltration curve of the Valiantzas method also illustrates the same behaviour as the curve differs from that derived using the two-point method (as shown in Figure 4). The reason for the underestimation of cumulative infiltration seems to be the constant value of C in the equation i.e. 0.007. For the same value of C, Ebrahimian et al. (2010) tested the Valiantzas method for clay silty loam and reported that this method was unsuitable for advance prediction. However, this method can give good results for infiltrated volumes for investigated soils. On the other hand, this study shows that the Valiantzas method is not appropriate for predicting advance as well as infiltrated volumes into silt loam soils.
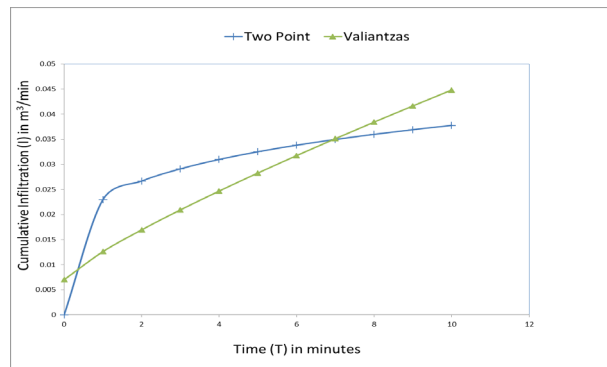
*Figure 4.* Cumulative infiltration curves by two-point and Valiantzas methods

**Upadhyaya and Raghuwanshi method.** The comparison of the predicted advance curve as illustrated in Figure 5 revealed that the performance of the method was poor as the curve produced by this method showed departure from the curve obtained from the measured data. The reason for poor performance of this method could be due to exponential assumption in the advance curve equation.
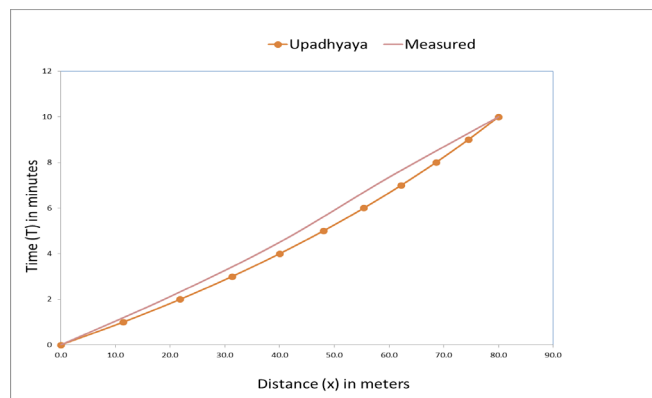


*Figure 5.* Upadhyaya method and measured data advance curves

The results of cumulative infiltration given by the Upadhyaya and Raghuwanshi method are presented in the Figure 6. From the cumulative infiltration curves, it is evident that this method underestimated the infiltration at initial time and overestimated the infiltration at longer time for silt loam soil. Apart from the graphical comparison, statistical indicators also showed unsatisfactory performance by this method as the Nash and Sutcliffe model indicated that efficiency was less than zero i.e. -5.25. At the intermediate opportunity time, the Upadhyaya method showed a departure of about 8 mm from the two-point method curve. The results of this study are in line with the findings of Khatri and Smith (2005).
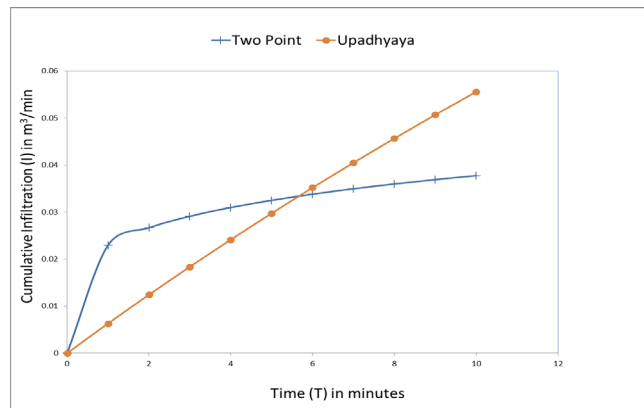
*Figure 6.* Cumulative infiltration curves by two-point and Upadhyaya methods

## CONCLUSION

The method suggested by Upadhyaya and Raghuwanshi showed poor performance as it under-predicted and over-predicted the cumulative infiltration for the initial time and indicated a longer time, respectively. This seems to have been due to the assumed value of 0.5 for parameter *r* used in this method. The Valiantzas method yielded unsuitable results for the soils under study. The predicted advance curves yielded from the use of the different methods were compared with the measured advance curve, and it can be deduced from the comparison that the trajectories reproduced by the two-point method compared favourably with those obtained from the measured advance curve. The Upadhyaya and Raghuwanshi and Valiantzas methods underestimated the advance trajectories except for time corresponding to the last advance point. On the basis of performance exhibited by the different methods under study, it is concluded and recommended that the tested methods must be evaluated before use for the soil under study. For future studies, it is suggested that these methods be tested for different irrigated soils with different values of constants in the equations.

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