Real time prediction of soil infiltration characteristics for the management of furrow irrigation

Kanya.L.Khatri and R.J. Smith

Cooperative Research Centre for Irrigation Futures, and National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba, Queensland, 4350, Australia

Corresponding author

Kanya Lal Khatri

Cooperative Research Centre for Irrigation Futures

Faculty of Engineering and Surveying

University of Southern Queensland

Toowoomba QLD, 4350

Australia

Ph: +61 7 4631 1713

Fax: +61 7 4631 2526

Email: khatrik@usq.edu.au, rajaln@yahoo.com

Abstract

The spatial and temporal variations commonly found in the infiltration characteristic for surface irrigated fields are a major physical constraint to achieving higher irrigation application efficiencies. Substantial work has been directed towards developing methods to estimate the infiltration characteristics of soil from irrigation advance data. However, none of the existing methods are entirely suitable for use in real time control. The greatest limitation is that they are data intensive.

A new method that uses a model infiltration curve (MIC) is proposed. In this method a scaling process is used to reduce the amount of data required to predict the infiltration characteristics for each furrow and each irrigation event for a whole field.

Data from 44 furrow irrigation events from two different fields were used to evaluate the proposed method. Infiltration characteristics calculated using the proposed method were compared to values calculated from the full advance data using the INFILT

computer model. The infiltration curves calculated by the proposed method were of similar shape to the INFILT curves and gave similar values for the cumulative infiltration up to the irrigation advance time for each furrow. More importantly the statistical properties of the two sets of infiltration characteristics were similar. This suggests that they would return equivalent estimates of irrigation performance for the two fields and that the proposed method could be suitable for use in real time control.

Introduction

Surface irrigation, especially furrow irrigation, is one of the most commonly used methods for irrigating crops and pastures in Australia and around the world due to the low cost, low energy requirements and improved aeration of the root zone. While well designed and managed surface irrigation systems may have application efficiencies of up to 95%, many commercial systems have been found to be operating with significantly lower and highly variable efficiencies. Previous research in the sugar industry (Raine and Bakker, 1996) found application efficiencies for individual irrigations ranging from 14 to 90% and with seasonal efficiencies commonly between 31 and 62%. More recently, Smith *et al.* (2005) reported application efficiencies in the cotton industry of similar range and magnitude.

The efficiency of surface irrigation is a function of the field design, infiltration characteristic of the soil, and the irrigation management practice. However, the complexity of the interactions makes it difficult for irrigators to identify optimal design or management practices. The infiltration characteristic of the soil is one of the dominant factors in determining the performance of surface irrigation applications and both spatial and temporal variations in the infiltration characteristic are a major physical constraint to achieving higher irrigation application efficiencies (Shafique and Skogerboe, 1983). The spatial and temporal variation commonly found in infiltration characteristics (Raine *et al.*, 1997) for a particular field also raises concerns regarding the adequacy of generalised design and management guidelines for surface irrigation.

A real time control system can overcome these spatial and temporal variations and a significant improvement in performance is achievable with real-time optimisation of individual irrigation events.

A study was undertaken by Raine *et al.* (1997) to identify the potential improvement in irrigation performance achievable through real time control strategies. The flow rate and application time required to maximise the application efficiency were calculated for each individual furrow and irrigation throughout the season. These management variables were then used in simulations of individual irrigations using the SIRMOD model. When the management parameters were optimised for each furrow and irrigation to simulate perfect real time control of individual irrigations, the average application efficiency increased significantly to 93% with a storage efficiency of 90%, without any significant difference in the distribution uniformity.

Azevedo *et al.* (1992) developed a computer model called SIRTOM (surface irrigation real time optimisation model) to estimate the infiltration parameters in real time from advance data. They used a one-dimensional optimisation technique called the Brent method to obtain the parameters k and f_o of the Kostiakov-Lewis equation. The parameter a was determined by the two point method.

Camacho et al. (1997) developed the infiltration parameter estimation (IPE) model for management and control of furrow irrigation in real time. This simulation model of furrow irrigation allowed estimation of infiltration parameters in real time. The model simulated irrigation using a kinematic-wave model. The objective was to find the infiltration parameters where the simulated water advance best matched the field measured data. The model estimated the parameters k and a of the Kostiakov–Lewis equation, whereas the parameter f_o must be calculated using indirect methods.

The major limitation of both the SIRTOM and IPE models is that they are data intensive and difficult to operate. The IPE model also requires the steady infiltration rate (f_o) to be measured separately.

The quest to extract the maximum information on soil infiltration from the minimum possible quantity of field advance data is of enormous importance, particularly for the automation of surface irrigation using real time control (Oyonarte et al., 2002). The greatest limitation of existing infiltration estimation methods is that the quality of estimates is directly related to the quantity of data used. Current evaluations require up to five in-field advance sensors located along the furrow length. Estimates can be further improved by inclusion of runoff data (Gillies and Smith 2005). The cost, installation and download of these sensors are significant components of the current data acquisition burden. More particularly the high data requirement is a major hindrance against the implementation of any form of real-time control.

There appears to be some potential to reduce the amount of data required to determine the event-specific infiltration characteristic and characterise the general infiltration equation by using a process of scaling. This approach formulates the relevant equation with the smallest possible number of variables and generalizes an infiltration equation for a broad range of applications.

Youngs and Price (1981) scaled the one-dimensional vertical infiltration into a range of soil materials with particles of different shapes and sizes. Warrick *et al.* (1985) used scaling to generalize the Philip quasi-analytical solution for one-dimensional infiltration. Warrick and Hussein (1993) used scaling techniques for the Richards equation of infiltration. Nachabe (1996) achieved a generalized numerical solution in terms of infiltration rate for one dimensional cases by scaling the $\theta - based$ (where θ is the soil volumetric water content) form of the Richards equation. Wu and Pan (1997) presented a generalized solution to infiltration from single-ring infiltrometers also by scaling. On the other hand, some researchers made an effort to present a general equation for infiltration in furrow irrigation. They looked at modified Kostiakov equation and attempted to introduce a factor such as inflow-rate, saturated and initial soil moisture content or wetted perimeter to generalize it. Sepaskhah and Afshar (2002) presented a general infiltration equation for furrow irrigation by multiplication of Q^{γ} (where Q and γ are the inflow rate and an arbitrary exponent respectively) in the Kostiakov-Lewis equation.

Finding a generalized solution for two-dimensional infiltration in furrow irrigation by scaling is a very useful way of reducing field data measurements required for prediction of the infiltration from irrigation advance. The work reported in this paper is part of a study directed at the development of a simple and practical real-time control system for surface irrigation. This paper presents a method of scaling for predicting the infiltration in furrow irrigation that uses minimum field data (inflow and one advance point), that provides infiltration characteristics in real time, and is applicable to a broad range of soils.

2. Description of the Proposed System

The underlying hypothesis for the method is that the shape of the infiltration characteristic for a particular field or soil is relatively constant despite variations in the magnitudes of the infiltration rate or depth of infiltration. For the purpose of real time control, the data required for obtaining soil infiltration characteristics for the irrigated furrows are reduced by scaling the infiltration parameters from an infiltration curve of known shape and one advance point measurement in each furrow. In this process a model infiltration curve (MIC), a new concept, is introduced. A furrow in the field is selected as the model furrow and its infiltration parameters are calculated from extensive advance and run-off data. Any infiltration equation can be used however for consistency with available simulation models the present study employs the Kostiakov-Lewis equation:

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

where I is the cumulative infiltration (m^3/m),

a, k, and f_o are the fitted parameters, and

τ is the infiltration time (min).

The cumulative infiltration curve calculated from these parameters is the model infiltration curve. Subsequently the model infiltration parameters can be used to estimate (by scaling) the cumulative infiltration curves for the whole field, and other irrigation events, using only one advance point for each of the remaining furrows or for each subsequent irrigation event.

In this method a scaling factor (*F*) is formulated for each furrow or event from a re-arrangement of the volume balance model (as used by Elliot and Walker (1982) and McClymont and Smith (1996)):

$$F = \frac{Q_o t - \sigma_y A_o x}{\sigma_z k t^a x + \dfrac{f_o t x}{1 + r}} \qquad (2)$$

where Q_o is the inflow rate for the corresponding furrow (m^3/min),

A_o is the cross-sectional area of the flow at U/S end of furrow (m^2) (determined by any appropriate method),

a, k, f_o are the infiltration parameters of the model furrow,

σ_y is a surface shape factor taken to be a constant (0.77),

σ_z is the sub-surface shape factor for the model furrow, defined as:

$$\sigma_z = \frac{a + r(1 - a) + 1}{(1 + a)(1 + r)}$$

r is the exponent from power curve advance function $x = p(t)^r$ for the model curve,

t (min) is the time for the advance to reach the distance x (m) for the corresponding furrow.

This scaling factor (*F*) is then applied in conjunction with the Kostiakov–Lewis infiltration model to scale the infiltration curves for the whole field (hereafter called the scaled infiltration curves) as follows:

$$I_s = F(k\tau^a + f_o\tau) \qquad (3)$$

where I_s is the scaled infiltration (m^3/m),

a, k, f_o are the infiltration parameters of the model furrow.

The scaling factor *F* as given by equation (2) can be defined as the ratio between the infiltrated volume as calculated by a volume balance in the trial furrow at t_{50} and the infiltrated volume as calculated by the parameters for the model furrow. The application of the factor (equation 3) follows from this definition and assumes each part (k and f_o) of the infiltration function be scaled in the same proportion. If for a particular soil type either of these parameters was considered to be constant and only the other part of the infiltration function was to be scaled, a different formulation of the volume balance equation (2) would be required.

For the proposed real time control system the infiltration estimates are required in sufficient time to allow selection and application of optimum times to cut-off while the irrigation event is under way. To achieve this, the advance times (t_{50}) taken at or near the mid-point down the furrow/field (x_{50}) are used in equation 2.

3. Evaluating the Infiltration Characteristics

3.1 Field data

The proposed method was tested and evaluated using data from 44 furrow irrigation events on two cotton fields (27 events for field T and 17 events for field C), irrigated by the growers using their usual practices. These fields were selected from the different farms across the cotton growing areas of southern Queensland for which irrigation water balance and irrigation advance data have been collected. The basis for selection was the relatively large number of events for each field.

Data collected for each event included the:

- furrow inflow rate;
- irrigation advance (advance times for various points along the furrow including the time for the advance to reach the end of the furrow); and
- physical characteristics of the furrow (length, slope, cross section shape).

The flow rate and irrigation advance were measured using the IRRIMATE™ suite of tools developed by the National Centre for Irrigation in Agriculture (NCEA), as described by Dalton *et al.* (2001). The data sets are summarized in Tables 1 and 2 for fields T and C, respectively.

3.2 INFILT Calculations

Infiltration parameters for each event of the fields were calculated from the full set of irrigation advance data using the INFILT program (McClymont and Smith, 1996). INFILT is a computer software package (one of the IRRIMATE™ tools) designed to calculate soil infiltration parameters using only inflow and advance data. The most common use of the program employs four or more advance points measured along the length of the furrow/field to determine best fit values for the three infiltration parameters *a, k* and f_o of the Kostiakov-Lewis equation (and the average cross sectional area of the flow $\sigma_y A_o$ if this term is not known). However use of the cross-sectional area as an input parameter when it is known (or can be estimated) results in improved estimates of the infiltration parameters. INFILT was the preferred method for this study because of its proven performance over time and over a range of soils and situations (Khatri and Smith, 2005). Although INFILT only provides an estimate of the infiltration parameters or infiltration function, these estimates will be hereafter termed the actual infiltration or actual parameters to distinguish them from the scaled infiltration.

Spreadsheet programs were developed to plot the cumulative infiltration curves for each irrigation event using the above actual infiltration parameters (*a, k* and f_o) in the Kostiakov–Lewis model.

3.3 Scaling Method

This proposed method uses the model curve concept to reduce the amount of data required for the estimation of the infiltration characteristics for each furrow and each irrigation event. Once the infiltration parameters of the model curve are known, this method requires inflow, cross-sectional area and only one advance point for each other furrow or event (measured mid-way down the furrow).

To test the proposed scaling method, it was applied to predict the infiltration characteristics for each event for the two fields T and C. Events T11 and C10 were selected as the model furrows for the two fields.

A spreadsheet program was developed to calculate the scaling factor (*F*) for each other furrow from equation (2), using the infiltration parameters of the selected model curve and the single advance point. Equation (3) was then used to calculate the scaled cumulative infiltration curves for each irrigation event.

3.4 Prediction of advance curves

To evaluate the accuracy of infiltration estimates given by the scaling method and the ability of the method to reproduce the irrigation advance (particularly the total advance time), the advance curves were predicted for each event using the scaled infiltration parameters in the volume balance model:

$$Q_o t = \sigma_y A_o x + \sigma_z k t^a x + \frac{f_o t x}{1+r} \quad (4)$$

Re-arranging gives:

$$x = \frac{Q_o t}{\sigma_y A_o + \sigma_z k t^a + (f_o t/(1+r))} \quad (5)$$

where x is the predicted advance distance (m) corresponding to time t (min),

σ_z is the sub-surface shape factor for the model furrow,

a, *k*, and f_o are the infiltration parameters of the model curve,

r is the power curve exponent for the model furrow,

Q_o and A_o are the flow rate (m^3/min) and cross-sectional area of the trial furrow (m^2), respectively.

4. Results and Discussion

4.1 Comparison of infiltration curves

The actual cumulative infiltration curves for fields T and C are presented in Figures 1a and 2a, respectively. In the case of field T (Figure 1a) all curves are similar in shape, typical of that for a cracking clay soil. The differences between the curves can be attributed to changes in soil moisture content and the degree of cracking. In the case of field C, Figure (2a) clearly shows that this field has a large variability in infiltration both spatially and temporally. The cumulative infiltration curves have very different shapes most probably reflecting a change in soil characteristics or soil types across this field.

The scaled cumulative infiltration curves for the two fields are presented in Figures 1b and 2b, respectively. From these figures it can be seen that the shapes of the scaled and actual infiltration curves (obtained by INFILT applied to a full set of data) are similar although some differences are evident. However they give similar estimates of the cumulative infiltration at various times up to the advance time for each trial.

To further illustrate the similarity between the scaled and actual infiltration, the scaled and actual cumulative infiltration curves for each furrow were compared individually. For example, in the case of field T, the actual cumulative infiltration curves and the scaled cumulative infiltration curves for the data sets (T11, T12 and T27) give identical predictions of the cumulative infiltration up to the advance times (662, 483 and 481 min, respectively) but diverge slightly beyond these times as shown in Figure 3(a). The comparisons were similarly good for most furrows at this site.

Similarly in case of field C, the actual and scaled cumulative infiltration curves for the data sets C5 and C9 show almost exactly similar predictions for the cumulative infiltration depth (closest to actual) up to the lower advance times (about 250 mins) as shown in figure 3(b).

Statistical comparison

While the above comparisons show that the scaling gives acceptable reproduction of the infiltration curves for most furrows, this is not necessarily the intent of the method. The scaling will be successful (for the purpose of inclusion in a real time control system) if the mean and variability of the cumulative infiltration over the field and/or over time is predicted successfully, that is, if the statistical properties are predicted successfully. This implies that the irrigation performance for that field will also be predicted successfully, the confirmation of which is the subject of a following paper (Khatri and Smith, 2006).

To assess this global correlation between the actual and scaled infiltration curves, the cumulative infiltration depths obtained at different times up to the advance time were analysed statistically.

Figure 4 shows the actual cumulative infiltration at a particular time (200 min) for each of the 27 irrigation events at field T plotted against the scaled cumulative infiltration for the same events. The linear trend line produced is very close to the 1:1 line giving the regression equation $I_{scaled} = 1.0149 I_{actual}$ and correlation coefficient $R^2 = 0.9259$. A T-test analysis for this same group of cumulative infiltration depths revealed that the means of actual and scaled infiltration depths at 200 min are not significantly different ($P \leq 0.05$).

The means of the scaled cumulative infiltrations at various times up to the advance time for the 27 irrigation events (Table 3) were also found to be very close to those for the actual curves, as shown in Figure 5. The Pearson correlation for the means was 0.99.

Similarly the variances (expressed as coefficients of variation) of the scaled and actual cumulative infiltration depths at these same times compare favourably. For the scaled infiltration CV is a constant 0.26 while for the actual infiltration the CV varies from 0.32 at 50 min down to 0.18 at 700 min. The cause for this difference is found in the three infiltration curves for furrows T17, T18 and T19. The irrigation advance for each of these furrows was very fast (< 200 min), indicating a relatively low infiltration rate for these furrows. However the cumulative infiltration curves predicted for these furrows by INFILT were of different character to the remaining curves for field T. While giving low infiltration at the early times these three curves must be considered unreliable when extrapolated to times greater than the advance times. The CV of the actual curves at 200 min is 0.25.

The strong correlations between the scaled and actual infiltration clearly demonstrate suitability of the scaling process for predicting the infiltration characteristics while using only a minimum of field data. Khatri and Smith (2005) have shown that previous methods based solely on one advance point are unreliable when applied across different soil types. This is because by use of particular infiltration equation they constrain the solution to particular soil types. By using the model infiltration curve, which is specific to the field in question, in conjunction with the single advance point, the above results indicate that greater accuracy and reliability can be obtained.

Varying the model curve

To determine the impact, if any, of selecting a different model curve (equivalent to selecting a different furrow for evaluation in the field), the method was tested using different model curves for both fields, showing low, medium and high infiltration. For instance in the case of field T, T22 and T27 were selected as the model curves and the scaled cumulative infiltration curves (obtained using these two different model curves) are shown in Figure 6. Likewise for field C, C12 and C15 were selected as the model curves and the cumulative infiltration curves scaled for this field (using the above two model curves) are shown in Figure 7.

From Figures 6 and 7, it is evident that selection of a different model curve does not have any significant impact on the scaled infiltration curves obtained for the both fields. Despite using different model curves they give almost identical estimates of the cumulative infiltration depth at various times up to the advance time (600 and 250 min for fields T and C, respectively). This indicates that the method is not limited to a specific model curve and hence selection of the furrow for full field evaluation is not critical to the process.

However as the model curve plays a highly significant role in the proposed method, it is important that the infiltration parameters of the model curve should be calculated as accurately as possible. This suggests the use of more rather than less data for evaluation of the model furrow including the use of run-off data in addition to advance data (Gillies and Smith, 2005).

4.2 Comparison of advance curves

The predicted and measured advance curves for field T are presented in Figures 8 and 9, respectively. From these curves it can be seen that the proposed method has predicted advance trajectories of similar form to the measured advance, with only minor differences in the final advance distances and at early times. This is to be expected because the method guarantees that the advance trajectory will pass through the selected mid-point, as shown in Figure 10 for T11, T12 and T22. A more complete evaluation of the ability to reproduce advance curves from the scaled infiltration, using the simulation model SIRMOD, will be given in a future paper (Khatri and Smith, 2006).

Consistency of p and r values

The volume balance equation (2) and the INFILT computer program assume that the irrigation advance follows the power curve equation:

$$x = p(t)^r \tag{6}$$

where t is the time taken for the wetting front to reach advance distance x, and p and r are fitted parameters. Further, the scaling method evaluated in this paper assumes that the exponent r is constant for a particular field.

Table 4 shows the values of p and r taken from the INFILT calculations for each irrigation event from the two fields. From Table 4 it is quite evident that the p values involve large variations, from 2.34 to 15.87. The table further shows that the r values exhibit a relatively small variation, ranging between 0.73 and 0.97 for field T, and between 0.62 and 0.85 for field C, indicating the consistency of this parameter for a whole field. Given that the scaling factor appears relatively insensitive to small changes in this parameter (see equation 2), hence using a constant value of r for a field is not unreasonable. The data in Table 4 also indicate that for a particular field the difference between the measured advance curves for the various events is described almost entirely by the coefficient p.

5. Conclusions

A method of scaling is proposed for the estimation of soil infiltration parameters in real time from a minimum of furrow irrigation advance data. It employs a model infiltration curve for the field and predicts the infiltration for each furrow using only one advance point measured mid-way down the furrow.

The proposed method was evaluated using data from 44 irrigation events from two fields having different infiltration characteristics and for which extensive advance data were available. The data for each field encompassed multiple furrows and multiple irrigations and define the extent of the spatial and temporal variability in the infiltration at each site.

The results from the evaluation indicated that:

- the scaled infiltration curves were of similar shape to the actual curves and gave nearly identical depths of infiltration up to the advance time for each furrow,
- the mean and variance of the scaled and actual infiltration at various times were similar, and
- the method was not sensitive to the choice of furrow used to give the model infiltration curve.

On the basis of these results it can be concluded that the proposed method has the potential for use in real time control and management of furrow irrigation.

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Table 1 Summary of data sets for field T

Furrow	Length (m)	Cross-sectional Area (m^2)	Flow rate (m^3/min)	Advance time (min)
T1	1120	0.050	0.3036	688
T2	840	0.050	0.3036	531
T3	840	0.0262	0.3036	531
T4	1120	0.050	0.3036	635
T5	1120	0.0262	0.3378	635
T6	1120	0.0262	0.3378	615
T7	840	0.0262	0.3546	457
T8	840	0.0262	0.3504	476
T9	1120	0.0262	0.3504	673
T10	1120	0.0262	0.3504	667
T11	1120	0.0262	0.3504	662
T12	1120	0.0262	0.3216	483
T13	840	0.0262	0.3216	316
T14	1120	0.0262	0.3216	446
T15	1120	0.0262	0.3216	448
T16	1120	0.0262	0.3678	383
T17	840	0.0262	0.3678	199
T18	840	0.0262	0.3678	195
T19	840	0.0262	0.3678	192
T20	1120	0.0262	0.2382	616
T21	1120	0.0262	0.2382	612
T22	1120	0.0262	0.4122	440
T23	1120	0.0262	0.4134	439
T24	1120	0.0262	0.3462	455
T25	840	0.0262	0.4272	312
T26	1120	0.0262	0.3876	498
T27	1120	0.0262	0.3876	481

Table 2 Summary of data sets for field C

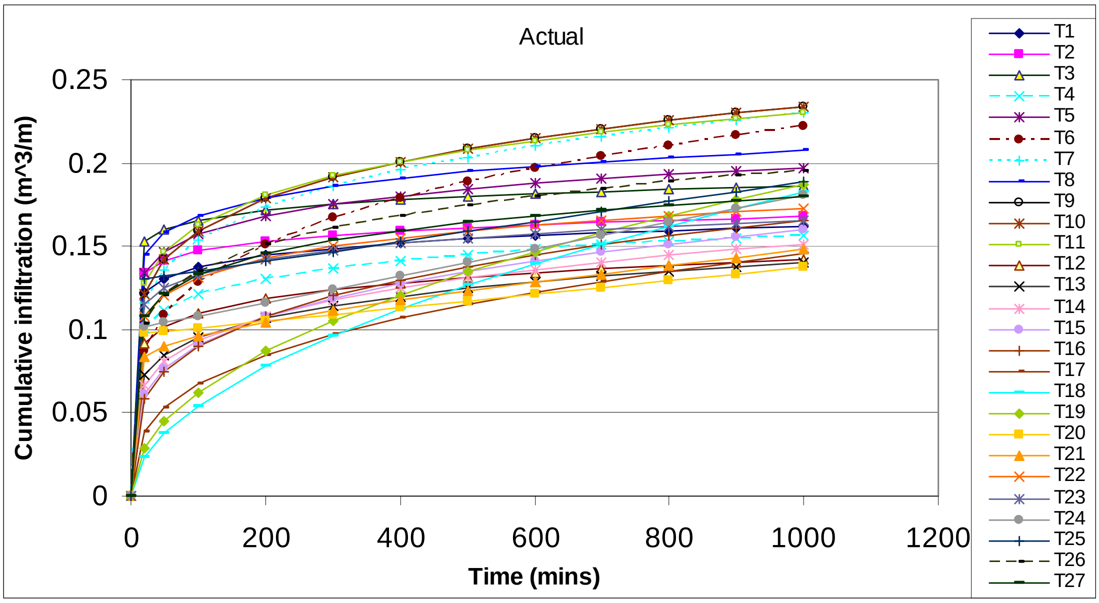
Furrow	Length (m)	Cross-sectional Area (m^2)	Flow rate (m^3/min)	Advance time (min)
C1	240	0.038	0.0498	273
C2	240	0.038	0.0498	307
C3	240	0.038	0.0498	336
C4	240	0.038	0.0498	427
C5	240	0.038	0.3126	277
C6	240	0.038	0.3126	367
C7	240	0.038	0.1566	238
C8	240	0.038	0.1566	246
C9	240	0.038	0.1566	210
C10	180	0.038	0.2244	186
C11	240	0.038	0.4752	109
C12	240	0.038	0.1134	164
C13	240	0.038	0.2286	126
C14	180	0.038	0.27	144
C15	240	0.038	0.27	189
C16	180	0.038	0.27	124
C17	240	0.038	0.27	171

Table 3 Mean of the actual and the scaled infiltration depths at various times up to advance time for field T

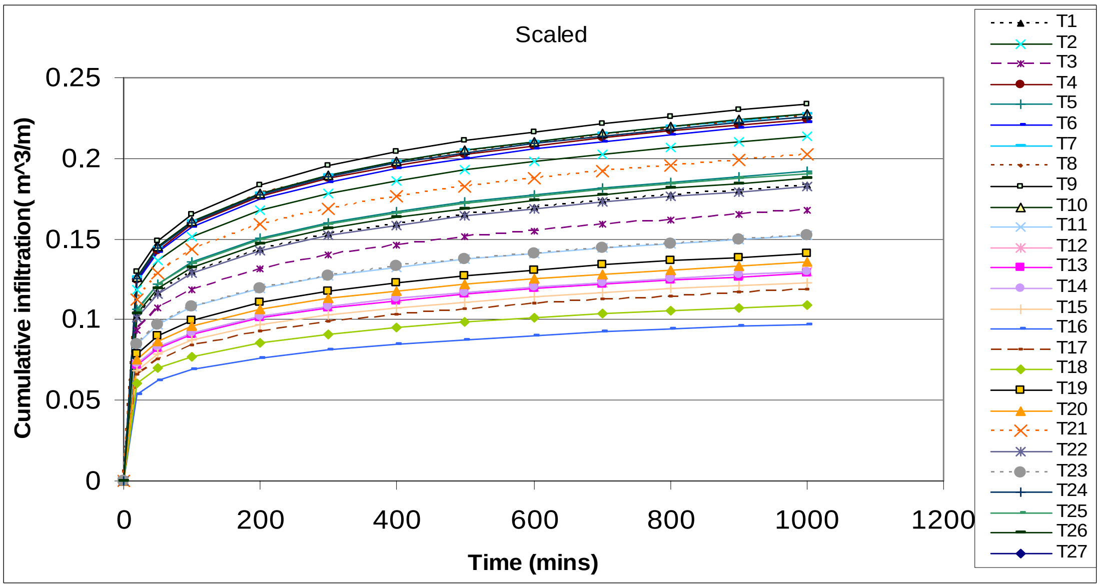
Time (min)	Actual mean infiltrated depth at various times (m^3/m)	Scaled mean infiltrated depth at various times (m^3/m)
0	0	0
50	0.111	0.112
150	0.129	0.132
200	0.135	0.138
300	0.146	0.146
350	0.150	0.150
400	0.154	0.153
500	0.162	0.158
600	0.169	0.162

Table 4 Showing *p* & *r* values for fields T and C

Field T			Field C		
	r	***p***		***r***	***p***
T1	0.856	4.115	C1	0.714	4.288
T2	0.939	2.311	C2	0.679	4.892
T3	0.939	2.311	C3	0.639	5.609
T4	0.898	3.363	C4	0.684	3.772
T5	0.898	3.363	C5	0.617	7.500
T6	0.791	7.019	C6	0.686	7.763
T7	0.833	5.094	C7	0.694	5.284
T8	0.911	3.044	C8	0.808	2.806
T9	0.826	5.116	C9	0.693	5.918
T10	0.855	4.184	C10	0.678	5.199
T11	0.850	4.398	C11	0.730	7.853
T12	0.887	4.640	C12	0.832	1.961
T13	0.853	6.222	C13	0.643	14.990
T14	0.816	7.709	C14	0.703	5.385
T15	0.799	8.549	C15	0.850	2.786
T16	0.777	11.073	C16	0.808	4.651
T17	0.751	15.875	C17	0.800	3.901
T18	0.765	14.910			
T19	0.729	13.603			
T20	0.927	2.906			
T21	0.879	3.962			
T22	0.884	5.178			
T23	0.904	4.598			
T24	0.905	4.436			
T25	0.971	3.214			
T26	0.841	6.035			
T27	0.815	7.257			

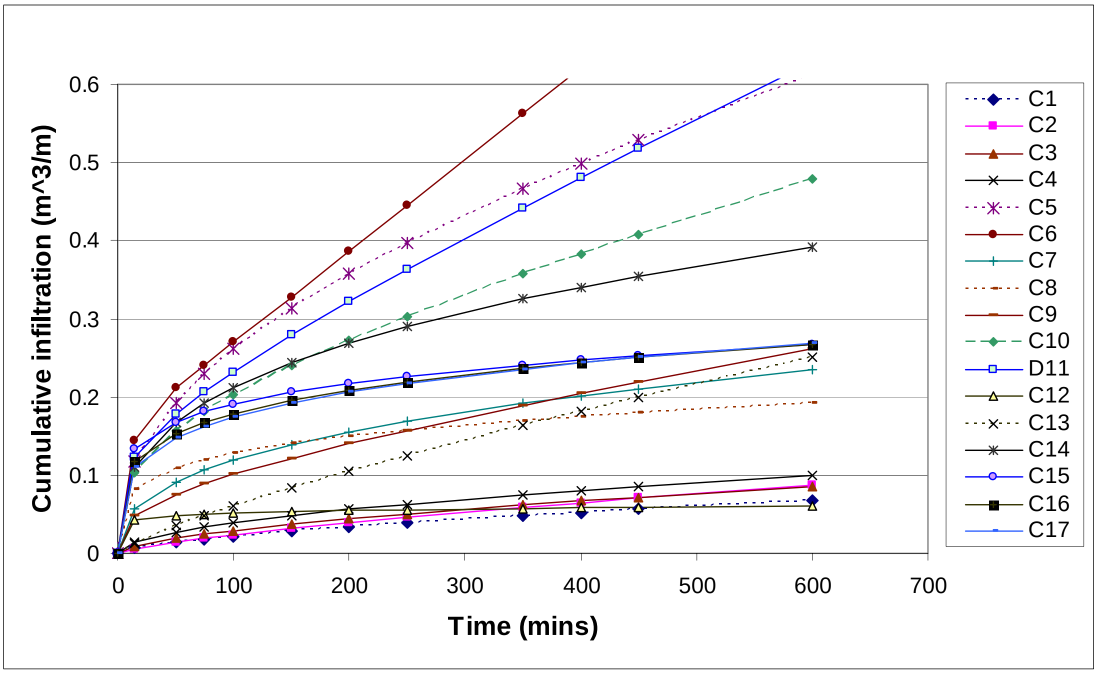


(a) Actual infiltration curves from INFILT infiltration parameters

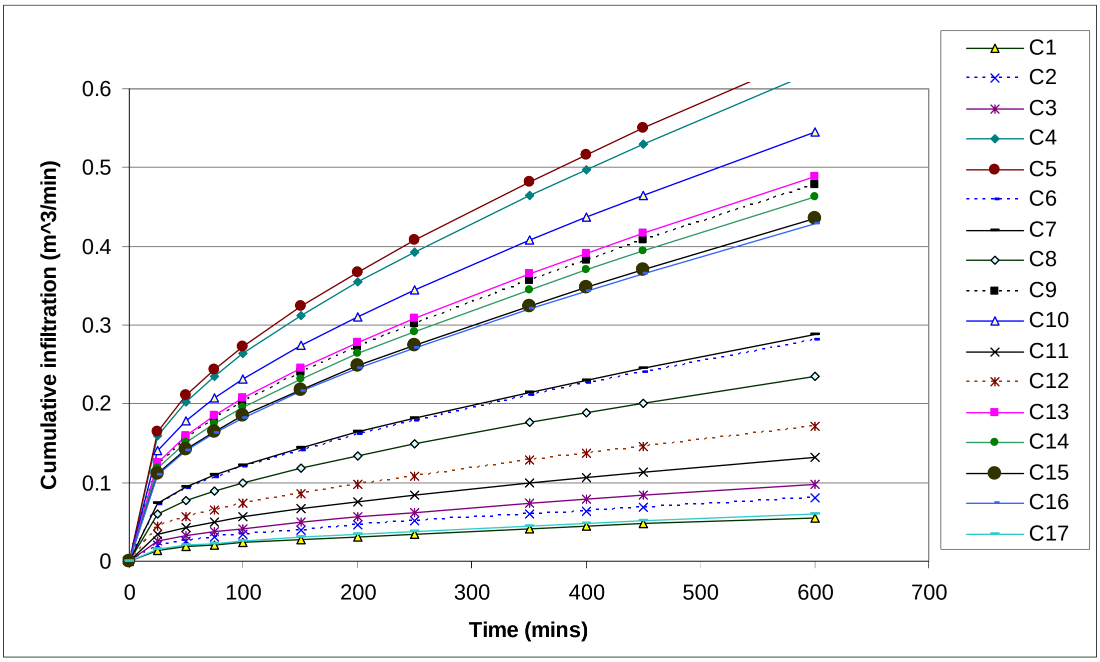


(b) Scaled infiltration curves

Figure 1. Cumulative infiltration curves for field T

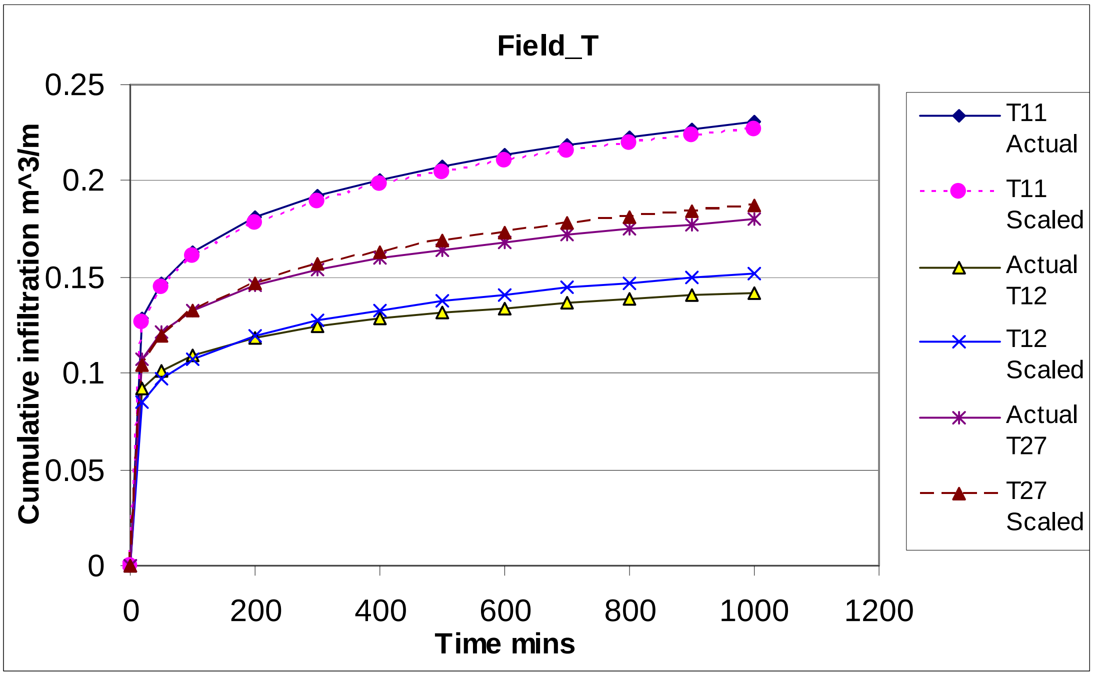


(a) Actual infiltration curves from INFILT infiltration parameters

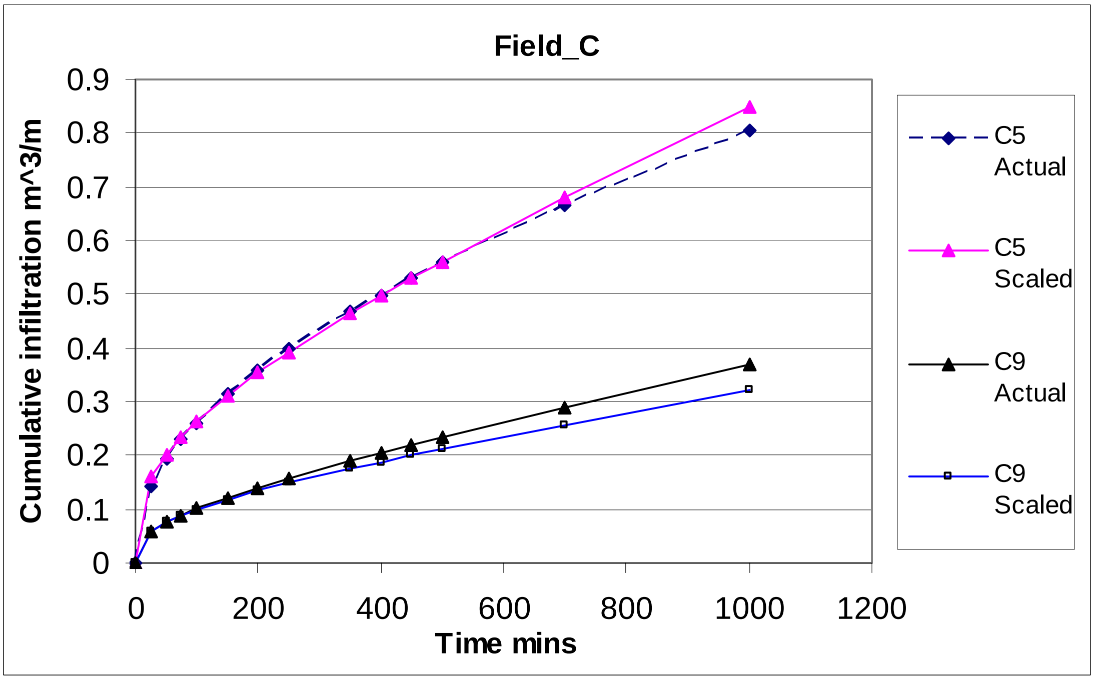


(b) Scaled infiltration curves

Figure 2. Cumulative infiltration curves for field C



(a) Field T



(b) Field C

Figure 3. Comparison of scaled and actual cumulative infiltration curves for individual furrows

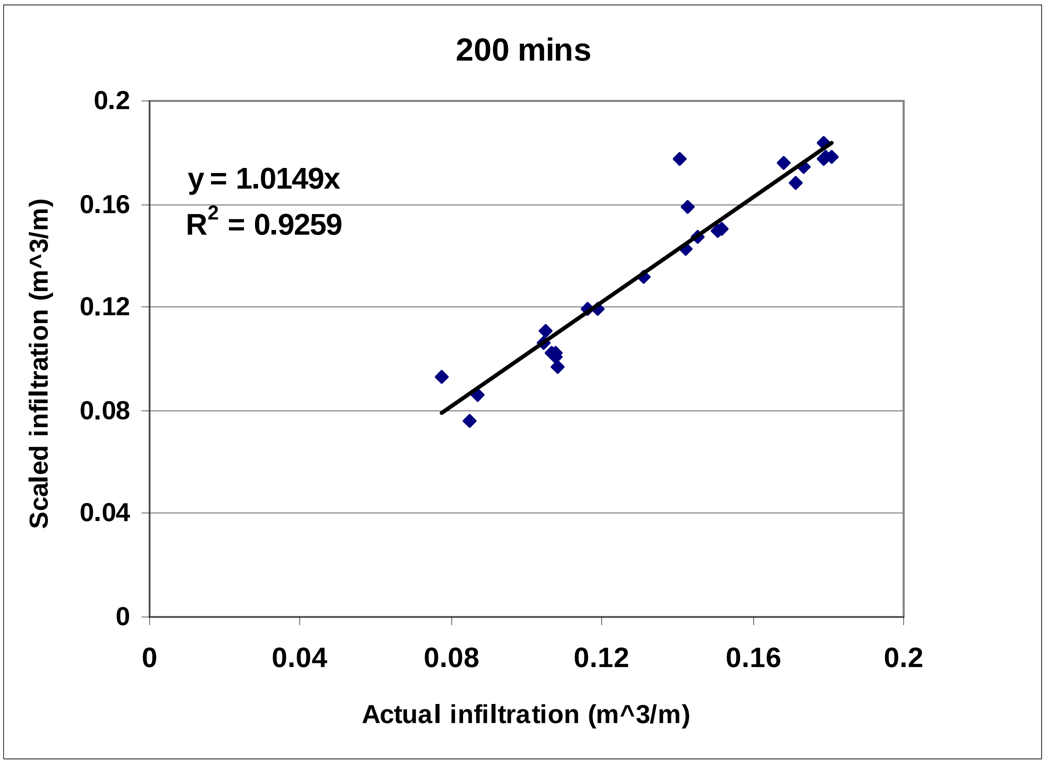


Figure 4. Scaled cumulative infiltration vs actual cumulative infiltration (at 200 min) for the 27 irrigation events at field T

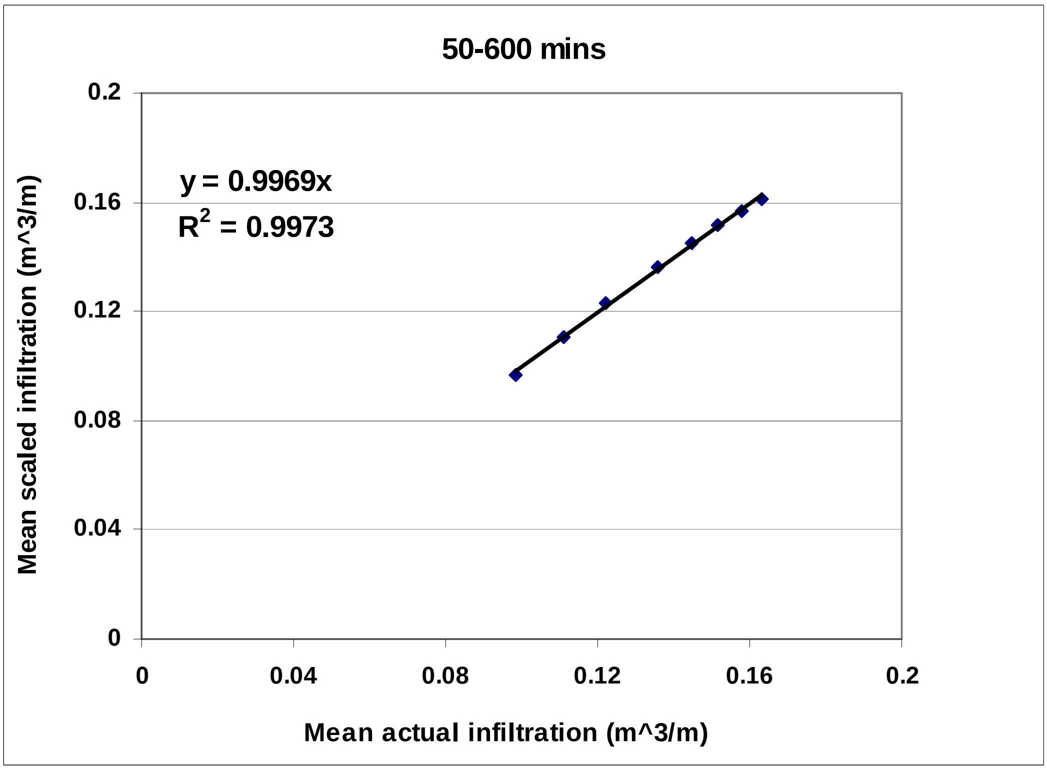
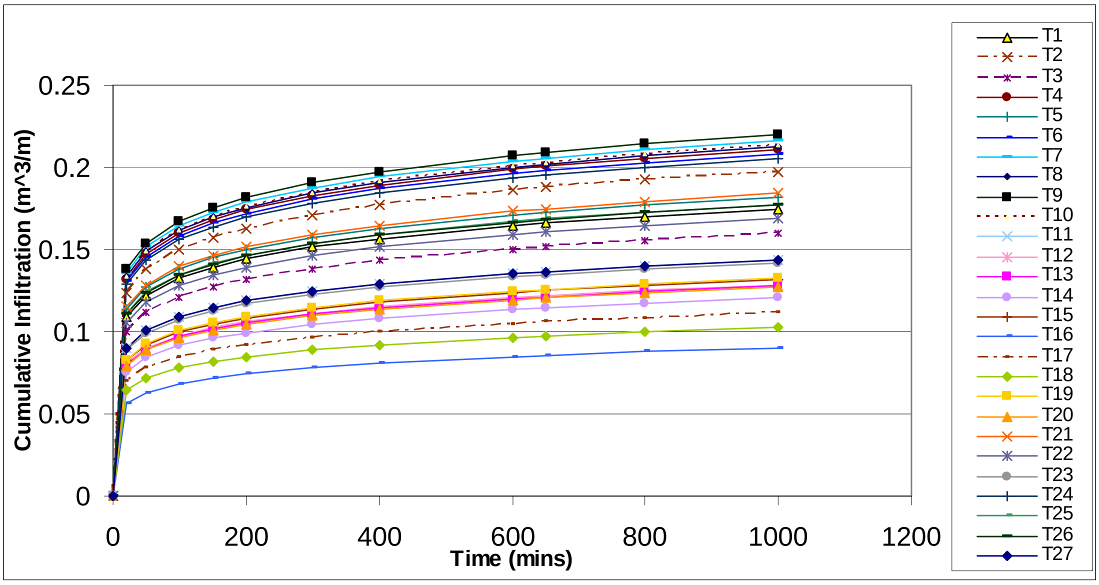
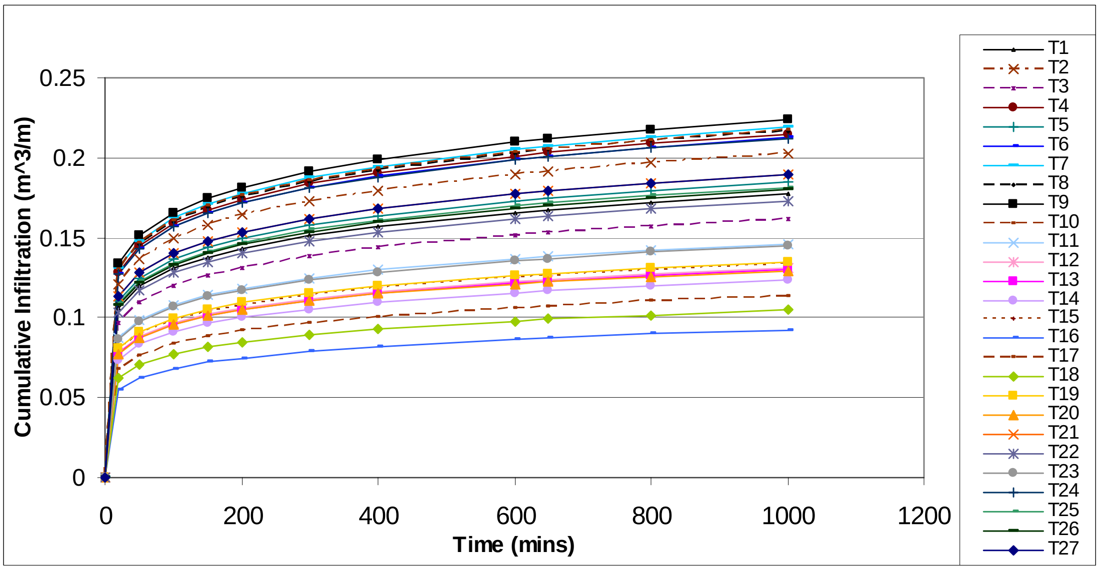


Figure 5. Mean of the scaled cumulative infiltrations vs the mean of actual cumulative infiltrations at various times for the 27 irrigation events at field T

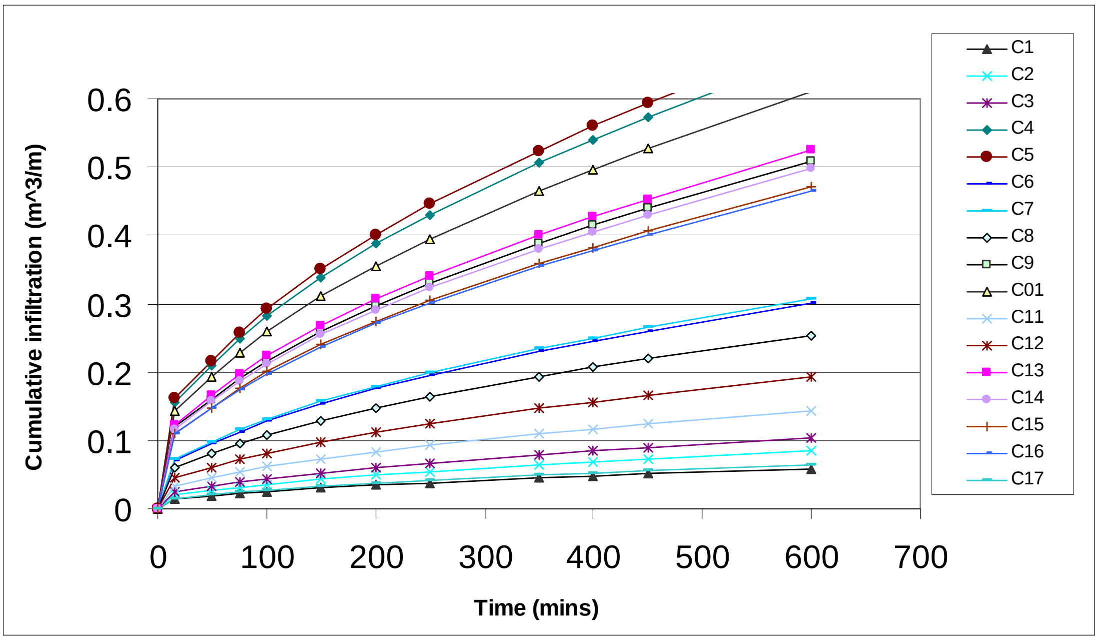


(a) Using furrow T22

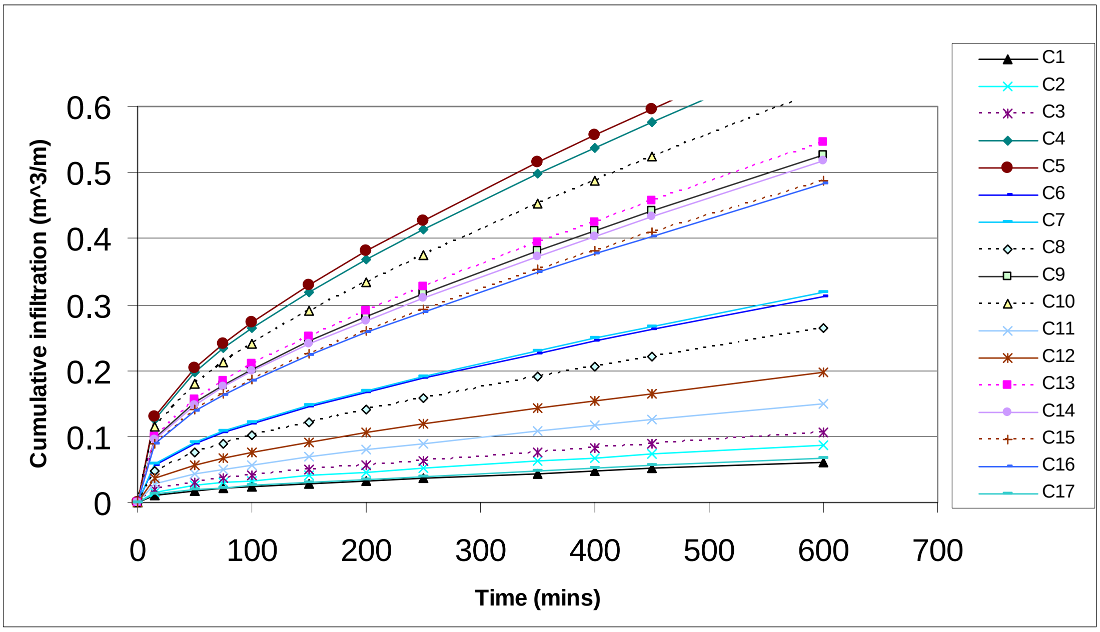


(b) Using furrow T27

Figure 6. Effect of using a different model furrow for field T



(a) Using furrow C5.



(b) Using furrow C9

Figure 7. Effect of using a different model furrow for field C

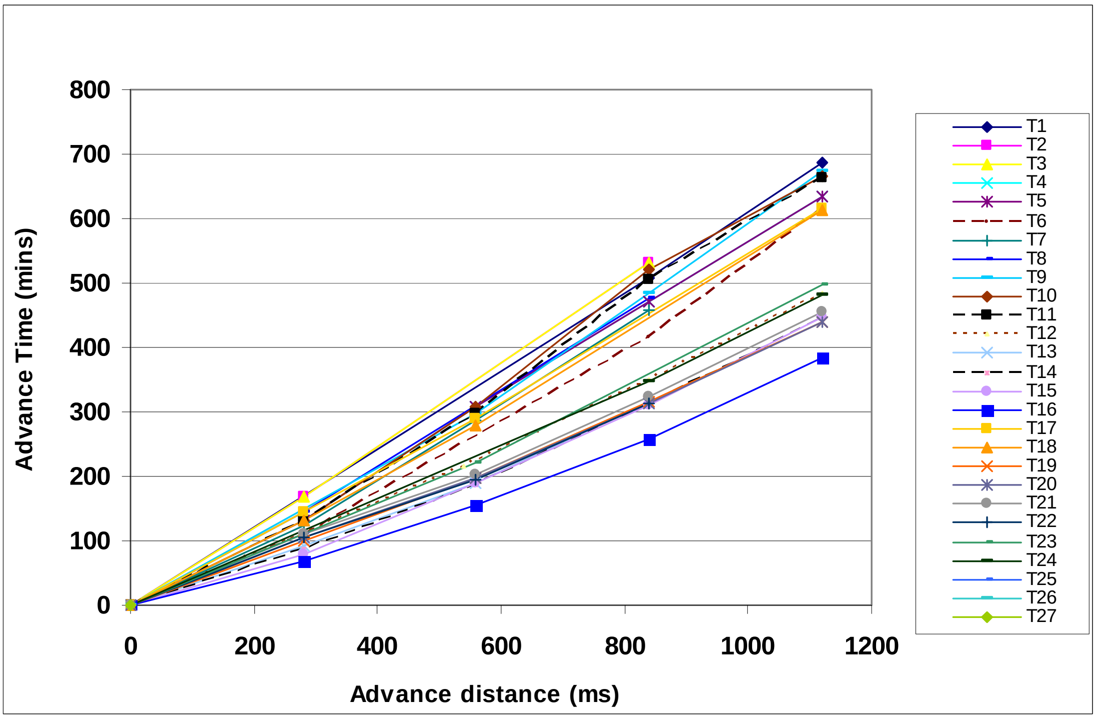


Figure 8. The advance curves predicted for field T using the scaled infiltration

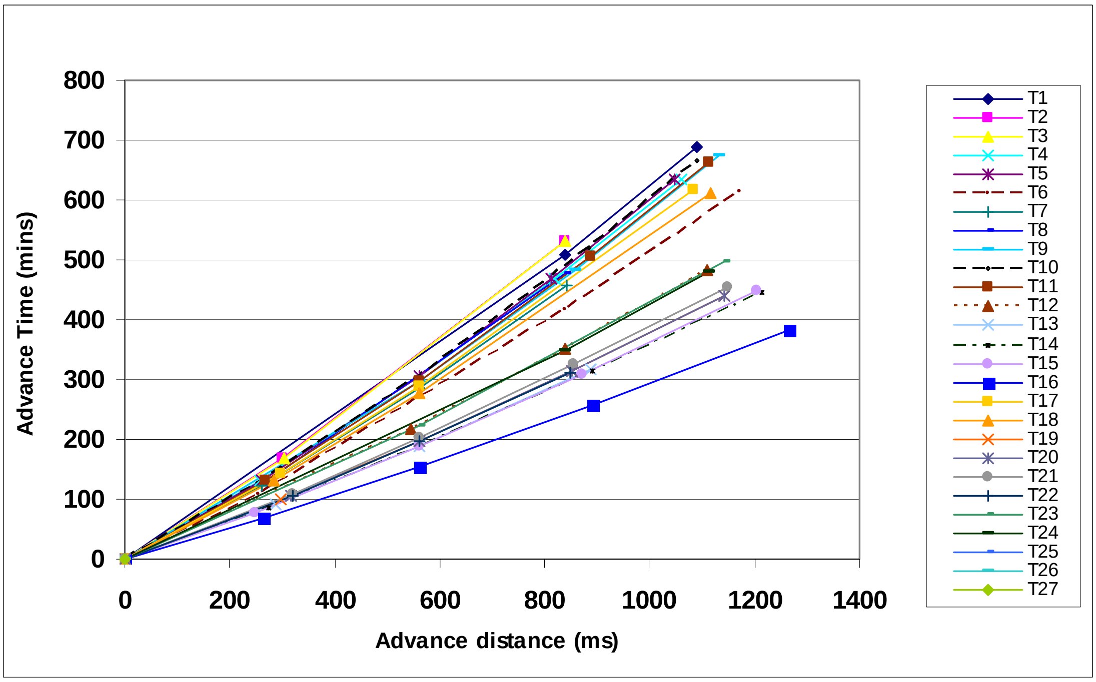


Figure 9. The measured advance curves for field T

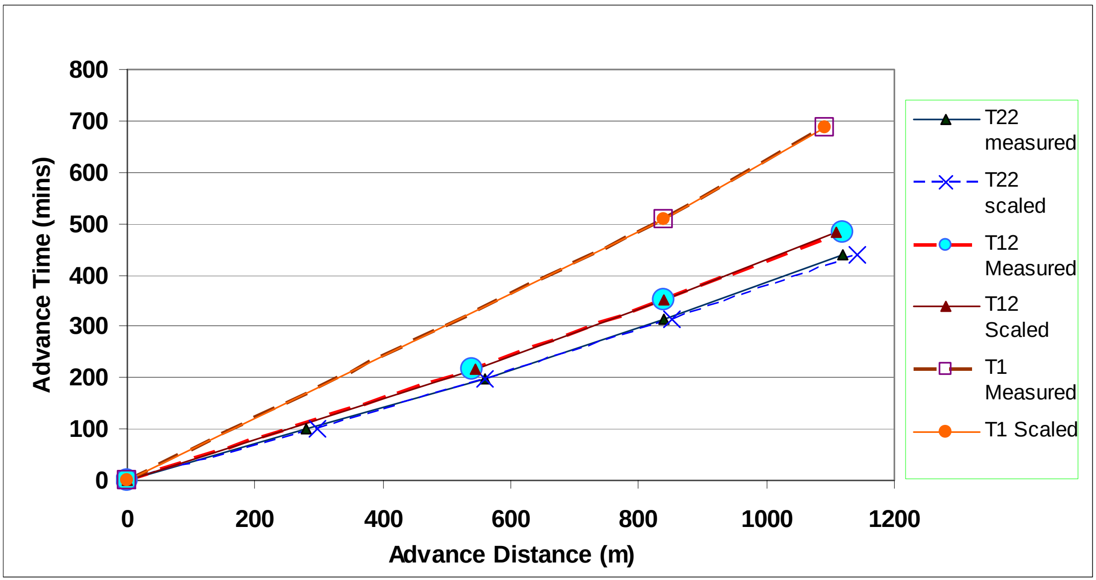


Figure 10. Comparison of individual advance trajectories for field T