Errors in predicting furrow irrigation performance using single measures of infiltration

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Abstract

Commercial performance evaluations of surface irrigation are commonly conducted using infiltration functions obtained at a single inflow rate. However, evaluations of alternative irrigation management (e.g. flow rate, cut-off strategy) and design (e.g. field length) options using simulation models often rely on this single measured infiltration function, raising concerns over the accuracy of the predicted performance improvements. Measured field data obtained from 12 combinations of inflow rate and slope over two irrigations were used to investigate the accuracy of simulated surface irrigation performance due to changes in the infiltration. Substantial errors in performance prediction were identified due to (a) infiltration differences at various inflow rates and slopes and (b) the method of specifying the irrigation cut-off. Where the irrigation cut-off at various inflow rates was specified as a fixed time identified from simulations using the infiltration measured at a single inflow rate, then the predicted application efficiency was generally well correlated with the application efficiency measured under field conditions at the various inflow rates. However, the predictions of distribution uniformity were poor. Conversely, specifying the irrigation cut-off as a function of water advance distance resulted in adequate predictions of distribution uniformity but poor predictions of application efficiency. Adjusting the infiltration function for the change in wetted perimeter at different inflow rates improved the accuracy of the performance predictions and substantially reduced the error in performance prediction associated with the cut-off recommendation strategy.

Introduction

Surface irrigation efficiency is affected by a range of factors including the inflow rate, soil infiltration characteristic, field length, target application volume, period of irrigation, surface roughness and field slope (e.g Walker and Skogerboe, 1987; Pereira and Trout, 1999). Furrow length and field slope are commonly considered design factors that are not easily modified. Similarly, the soil infiltration characteristic and surface roughness are essentially fixed factors over which the irrigator has limited, if any, control. However, inflow rates, target application volume and time to irrigation cut-off are generally considered management factors which can be varied between events by the irrigator and hence, used to improve irrigation performance.

The soil infiltration characteristic is one of the most important determinants of surface irrigation performance (McClymont and Smith, 1996; Oyonarte et al., 2002). However, infiltration often varies temporally and spatially and thus makes the management of surface irrigation a complex process (Camacho et al., 1997; Raghuvanshi and Wallender, 1997; Rasoulzadeh and Sepaskhah, 2003). The adjustment of furrow inflow rates and cut-off times is commonly used under commercial conditions to optimize irrigation performance in response to changes in soil infiltration and target application volumes (Raghuvanshi and Wallender, 1997; Raine et al., 1997 & 1998; Smith et al., 2005; Zerihun et al., 1996). However, the optimization of surface irrigation performance typically involves the use of field data often obtained from a single irrigation event.

Measured irrigation advance data is commonly used to calculate the soil infiltration function using an inverse solution of the volume balance equation (e.g. Walker and Skogerboe, 1987; McClymont and Smith, 1996; Gillies and Smith, 2005). This data is subsequently applied within a simulation model to reproduce the measured irrigation in a calibration-validation process (Pereira and Trout, 1999; Raine et al., 2005). Assuming adequate model calibration, alternative irrigation strategies (e.g. flow rates and time to cut-off) are then evaluated to identify an appropriate "optimal" irrigation recommendation.

The only commercial surface irrigation evaluation service currently provided in Australia (Raine et al., 2005) uses the surface irrigation model SIRMOD II (Walker, 2001). The service undertakes field evaluations and provides recommendations on improved management and design parameters. While there are a range of options available, the most common service involves measuring a single irrigation (i.e. single flow rate and infiltration condition) and using this data to make recommendations regarding inflow rate and cut-off time to improve performance. SIRMOD II has the capability to modify the infiltration function based on changes in furrow wetted perimeter and inflow discharge. However, this feature is rarely used in practice due to the parameterization requirements. The failure to adjust the infiltration function in response to changes in the simulated inflow has raised concerns over the accuracy of "optimal" recommendations based on different flow rates and cut-off strategies. Due to labour considerations, recommendations for cut-off are sometimes formulated around labour shifts (e.g. "cut-off after 8 or 12 hours") rather than based on water advance to specified distances along the field (e.g. "cut-off when water reaches the end of furrows"). Hence, the objectives of this study were to investigate the effect of (a) inflow rate and slope on furrow infiltration, (b) infiltration variation on the accuracy of the irrigation performance prediction when the operator has only measured the infiltration function at a single flow rate and slope and (c) time-based and distance-based irrigation cut-off recommendations on the accuracy of irrigation performance predictions at different inflow rates.

Method and Materials

Evaluation data

The field data used in this evaluation was obtained from Mwatha and Gichuki (2000) who conducted furrow irrigation trials in the Bura Irrigation Scheme, Kenya. The soils in the Bura area are shallow sandy clay loams and heavy cracking clays overlying saline and alkaline subsoils of low permeability. The irrigation water is pumped from the Tana River and conveyed through canals to smallholder irrigation fields where it is siphoned into 0.9 m spaced furrows. Data from two irrigations (first and fifth) during the 1989 growing season were collected from four irrigated cotton plots (lengths of 275-300 m) with average slopes of 0.09, 0.13, 0.25 and 0.31 % (Table 1). All data was collected from plots located on the same soil type (Mwatha and Gichuki, 2000). The first irrigation had a deficit of 70 mm and the fifth irrigation had a deficit of 63 mm as measured by the difference in the volumetric soil moisture content taken at 50 m distances along the field before the irrigation and two days after irrigation (Mwatha and Gichuki, 2000). Within each plot there were three inflow rate (1.5, 2.0 and 3.0 L s^{-1} $furrow^{-1}$) treatments and data was collected from four furrows in each treatment. Inflow was measured using Parshall flumes and for the purpose of this analysis it was assumed there was no inflow variability.

{insert Table 1 near here}

Computation of infiltration parameters

Mwatha and Gichuki (2000) reported the fitted parameters (p and r) for a power function describing the measured water advance (average of four furrows) for each of the irrigation events:

$$x = p(t_a)^r \qquad \text{Equation 1}$$

where t_a is the time taken for the water to reach advance distance x. These data (Table 1) were used to calculate irrigation advance points and to calculate the fitted parameters (a, k, and f_0) for the modified Kostiakov infiltration function using the infiltration model INFILT (McClymont and Smith, 1996):

$$Z = k(\tau)^a + f_o(\tau) \qquad \text{Equation 2}$$

where Z is the cumulative infiltrated volume per unit furrow length ($m^3\ m^{-1}$) and τ is the infiltration opportunity time (min). However, large differences in the shape of the infiltration functions were observed possibly due to the short periods of advance data available for some furrows. The a, k and f_o parameters are highly inter-related and, particularly where only short periods of advance data are available, there is large uncertainty in these fitted parameters. This may lead to interpretative differences in the shape of the cumulative infiltration function which are related more to the calculation method rather than observed physical differences (Holzapfel et al., 2004). Hence, to ensure that the shape of the infiltration functions were not influenced by the calculation method, the infiltration functions were calculated using a model infiltration function and scaling process (Khatri and Smith, 2006). This approach involved the arbitrary selection of a single measured infiltration function (termed the "model infiltration function") and the calculation of a scale factor (F) for other events conducted at the same time but on different field slopes and/or with different flow rates.

The infiltration function calculated for the 2.0 L s^{-1} and 0.13 % field slope event for each irrigation was selected as the model infiltration function and the modified Kostiakov fitted parameters were calculated using the infiltration model INFILT (McClymont and Smith, 1996). The scaling factor (F) for each of the other treatments was then obtained from the volume balance equation as:

$$F = \frac{Q_o t - \sigma_y A_o x}{\sigma_z k t^a x + \frac{f_o t x}{1+r}} \qquad \text{Equation 3}$$

where Q_o is the inflow rate for the specific furrow (in $m^3\ min^{-1}$), σ_y is a surface shape factor usually taken to be constant at 0.77, a, k, and f_o were the modified Kostiakov equation fitted parameters derived for the model infiltration function, r is the exponent from the power curve advance function for the furrow, t is the advance time (in min) for a known advance distance x (in m) in the furrow and σ_z is the sub-surface shape factor for the model infiltration furrow and calculated as:

$$\sigma_z = \frac{a + r(1-a) + 1}{(1+a)(1+r)} \qquad \text{Equation 4}$$

The cross-sectional area of flow (A_o) was calculated using the furrow geometry measurements provided by Mwatha and Gichuki (2000) and the Manning equation. As all irrigations were conducted on bare furrows the Manning coefficient was assumed to be 0.04 (Walker, 2001). The scale factor was then used to calculate the cumulative infiltration (Z) for the irrigation using:

$$Z = F \{k(\tau)^a + f_o(\tau)\} \qquad \text{Equation 5}$$

Both equations 3 and 5 assume that the infiltration variation involves variation of both k and f_o, an assumption that might not apply to all soils.

Effect of infiltration function on the accuracy of performance evaluation

A framework for evaluating the effect on performance of not adjusting the infiltration function in response to changes in inflow is shown in Figure 1. Performance evaluations were conducted using the surface irrigation model SIRMOD II (Walker, 2001) and the performance indices used were the application efficiency (E_a), requirement efficiency (E_r) and distribution uniformity (DU) as calculated by SIRMOD II (Walker, 2001). In step 1, the evaluations simulated the measured irrigations by setting the simulation flow rate (Q_{sim1}) equal to the flow rate at which the infiltration function was measured ($Q_{infilt1}$). The Manning n value was adjusted from the default value (i.e. n = 0.04) until the simulated advance time at the end of the field was equal to the measured advance time (McClymont et al., 1996). In each case, the adjustments were small (i.e. < 0.02) and within the reasonable values for bare furrows (ASAE, 2003).

{Insert Figure 1 about here}

To evaluate the impact of varying Q_{sim} without adjusting the infiltration function (Step 2 of Figure 1), Q_{sim} was then set to either 1.5, 2.0 or 3 L s^{-1} without changing the infiltration function. It is at this point that commercial consultants commonly make a decision on "optimal" recommendations regarding inflow rates and cut-off times. In this case, the simulation was conducted with the cut-off time (t_{co}) being arbitrarily set equal to the advance time (t_L). However, in formulating the cut-off recommendation for the irrigator, the consultant may specify either (a) that the water should be cut-off after a fixed period of irrigation (i.e. time based), (b) when the water has reached a specified distance along the field (i.e. distance based) or (c) some combination of these methods as when a fixed time is specified after the water has reached the end of the field. Hence, step 3 of this evaluation (Figure 1) involved simulating the irrigation that would have occurred had the grower adopted either a time or distance based recommendation but where the infiltration function used was appropriate to the recommended inflow rate (i.e. $Q_{sim2} = Q_{infilt2}$). The two options for cut-off were simulated: (a) cut-off set equal to the advance time (t_L) identified when this flow rate (Q_{sim2}) and the original infiltration function ($Q_{infilt1}$) were used in the simulation and (b) cut-off set equal to a specified advance distance (i.e. the end of the field) but when the infiltration function appropriate for this flow rate (i.e. $Q_{infilt2}$) was used in the simulation. Evaluations were conducted for each of the 24 combinations of slope and inflow rate for which data was available.

In this paper, infiltration functions and performance parameters calculated directly from the measured inflow rates and advance data are referred to as the “measured” parameters to distinguish these from the performance parameters obtained from simulations where the simulated inflow rate is different to that at which the infiltration function was calculated. Similarly, the difference in the performance parameters calculated using the measured infiltration functions and where the simulated inflow rate is different to that at which the infiltration function was calculated is referred to as the “error” in performance prediction.

Effect of adjusting infiltration for wetted perimeter differences

The inflow rate applied to furrows influences infiltration by altering both the depth of water in the furrow and the wetted perimeter (Enciso-Medina et al., 1998; Schmitz, 1993). Many workers (e.g. Strelkoff and Souza, 1984; Camacho et al., 1997; Walker, 2001; Mailhol et al., 2005) have suggested that the accuracy of simulated irrigations can be improved by modifying the infiltration function to reflect differences in wetted perimeter at various inflow rates. To evaluate the impact of modifying wetted perimeter on the accuracy of the performance predictions, Step 2 above was repeated but where the infiltration measured in step 1 was modified according to the approach of Strelkoff and Souza (1984) using:

$$Z_{sim2} = Z_{sim1}\left\{\frac{WP_{sim2}}{WP_{sim1}}\right\}^{b} \qquad \text{Equation 6}$$

where WP_{sim1} is the wetted perimeter (in m) and Z_{sim1} is the infiltration at Q_{sim1}, WP_{sim2} is the wetted perimeter (in m) and Z_{sim2} is the calculated infiltration adjusted for wetted perimeter at Q_{sim2} and b is an empirical exponent. In this study, the exponent was assumed to be 0.6 which is consistent with the value proposed by Alvarez (2003) and subsequently used by Mailhol et al. (2005). However, Oyonarte et al. (2002) measured a value of 0.6 for early season events and 0.3 for later season irrigations.

Results and Discussion

Effect of inflow rates and furrow slope on infiltration

The scaled cumulative infiltration curves (Figure 2 and 3) indicate that infiltration generally increased with increases in inflow rate and decreased with increasing slope. However, the trends were much more consistent for the fifth irrigation (Figure 3) than for the first irrigation (Figure 2). The differences in both the measured advance parameters (Table 1, t_L and r) suggest that infiltration variability was larger in the first irrigation and may be masking some of the expected hydraulic effects of changes in flow rate and slope. The larger advance and infiltration variations observed in the first irrigation suggests that the factors (e.g. cultivation, initial soil moisture content) influencing variability were more dominant early in the season.

The effect of slope and inflow rate on infiltration is broadly consistent with the observations of others (e.g. Holzapfel et al., 2004) and is presumably related to the effect of these factors on flow depth and wetted perimeter. As the slope decreases and the inflow increases the flow depth and wetted perimeter generally increase resulting in higher infiltration rates. Note that for the fifth irrigation events (Figure 3) conducted on higher slopes (>0.13%) there was little difference between the 2.0 and 3.0 L s^{-1} infiltration functions suggesting that the difference in depth and wetted perimeter for these flow rates was small. However, for the low slope (0.09%), the difference between the infiltration functions at each inflow rate was substantial.

{Insert Figures 2 and 3 about here}

Effect of infiltration function on the accuracy of performance evaluation

The results of the performance evaluations conducted using the 1.5 L s^{-1} flow rates on the 0.09 and 0.31 % slope plots are shown in Table 2 as an example only. In this example, the performance of the simulations conducted to evaluate the measured irrigation events (i.e. $Q_{sim1} = Q_{infilt1}$) varied substantially with application efficiencies (E_a) ranging from 39 to 99 %, requirement efficiencies (E_r) from 80 to 100% and distribution uniformities (DU) from 63 to 73%.

{Insert Table 2 about here}

Evaluations of performance for different inflow rates using the $Q_{infilt1}$ infiltration functions (i.e. $Q_{sim2} \neq Q_{infilt1}$) generally suggested that substantial improvements in E_a and DU could be obtained by changing inflow rates. However, the actual change in performance that would have been achieved had these inflow rates been applied (i.e. $Q_{sim2} = Q_{infilt2}$) was highly variable and heavily dependent on both the cut-off strategy applied and the difference in the infiltration functions at the two inflow rates. For example, a recommendation to apply 3.0 L s^{-1} to the 0.09% slope field was predicted to achieve an E_a and DU of 69 and 75 % respectively for the first irrigation, and an E_a and DU of 63 and 75 % respectively for the fifth irrigation (Table 2). However, for the first irrigation, applying 3.0 L s^{-1} would have resulted ($Q_{sim2} = Q_{infilt2}$) in an E_a of 65-86 % and a DU of 88-95 % depending on whether the cut-off recommendation was time based or distance based. However, for the fifth irrigation, the same strategies would have produced an E_a of only 27 or 42 % and a DU of 0 or 65 %. Hence, increasing the flow rate in the fifth irrigation event would have reduced the performance rather than increasing it as predicted. Similarly, using a time based cut-off strategy based on the $Q_{infilt1}$ simulation would have led the farmer to cut-off the inflow before the water reached the end of the furrow resulting in substantial under-irrigation.

The comparative performance data for all 24 combinations of flow rate and slopes indicate that the error in prediction was generally greater in the first irrigation (Figure 4) than in the fifth irrigation (Figure 5). This is consistent with the larger variability in advance observed (Table 1), and the consequent differences in the infiltration functions calculated for the first irrigation (Figure 2). Hence, variability in infiltration is a significant determinant of performance evaluation accuracy using predictive modelling and suggests that some account of both spatial and temporal variability is required to adequately characterise predictive accuracy at the field scale (Schwankl *et al*., 2000).

{Insert Figures 4 and 5 about here}

Effect of cut-off recommendation on the accuracy of performance prediction

The main effect of the irrigation cut-off strategy recommendation was to trade-off the predictive accuracies of E_a and DU. For the fifth irrigation, approximately 88% of the E_a predictions using the time based recommendation were within 10% of the expected performance under the field conditions but only 25% of the DU values for the same simulations were within ±10% (Figure 5a). Conversely, using the distance based recommendation for cut-off time (Figure 5b) resulted in only 42% of the E_a predictions, but all of the DU predictions, being within ±10% of the values calculated using the infiltration function appropriate to the inflow.

Time based recommendations for cut-off generally resulted in predictions of E_a which were well correlated with the E_a that would have been obtained using the appropriate infiltration function (Figures 4a and 5a). In this case, volume balance errors associated with the differences in the infiltration function used did not affect the total volume of water applied but did affect the relative proportions of deep drainage and tail water. The main effect of the error in infiltration when using a time based cut-off was the impact on the total distance over which the water advanced. Applying the water for a fixed time on a soil with a larger cumulative infiltration function than used in the prediction resulted in water advances which did not reach the end of the field. In these cases, the lack of water application over substantial areas of the field resulted in widely ranging DU values (0-90%) which were poorly correlated with the predicted DU values (generally 60-90%).

Distance based recommendations for cut-off generally resulted in predictions of E_a which were poorly correlated with the E_a that would have been obtained using the appropriate infiltration function (Figures 4b and 5b). However, DU was better predicted when the cut-off was based on distance rather than time. Using the distance based cut-off recommendation resulted in the whole field being irrigated but reduced the accuracy of prediction for the total water required to be applied. Using a distance based recommendation for cut-off was also found to generally under-predict E_r.

Effect of adjusting infiltration for differences in wetted perimeter

Adjusting the infiltration function according to flow rate and wetted perimeter differences was found to substantially improve the accuracy of the performance index prediction (e.g. compare Figures 4 and 5 with Figures 6 and 7). There was also a much reduced effect of the irrigation cut-off strategy (e.g. time based versus distance based) on the accuracy of the performance indices. This suggests that the failure to adjust the infiltration function due to changes in the wetted perimeter was a major determinant of predictive errors in the earlier analyses (e.g. Figures 4 and 5). Residual errors in the performance prediction after adjustment for the wetted perimeter effects could be expected to be due to in-field spatial infiltration variability. The use of the b = 0.6 exponent value in equation 6 would also appear to be appropriate for this soil and contrary to the findings of Oyonarte et al. (2002) there does not appear to be any justification for different exponent values for the early and later irrigations in the season.

{Insert Figures 6 and 7 about here}

Conclusions

Infiltration functions obtained from 24 combinations of slopes and inflow rates were used to investigate the effect of infiltration differences on the accuracy of simulated surface irrigation performance evaluations. Substantial differences in infiltration were measured between each irrigation event, inflow rate and field slope. The errors in simulated performance were found to be a function of the strategy adopted for irrigation cut-off. Using a time based cut-off strategy generally produced reasonable estimates of E_a but poor estimates of DU. Conversely, distance based cut-off strategies resulted in adequate predictions of DU but poor predictions of E_a. However, where the infiltration was adjusted for changes in the wetted perimeter at different flow rates, then the accuracy of the performance predictions was substantially improved and the effect of cut-off strategy on the accuracy of the predictions greatly reduced.

Acknowledgement

The data used in this research was collected by Mwatha and Gichuki (2000) and is greatly appreciated.

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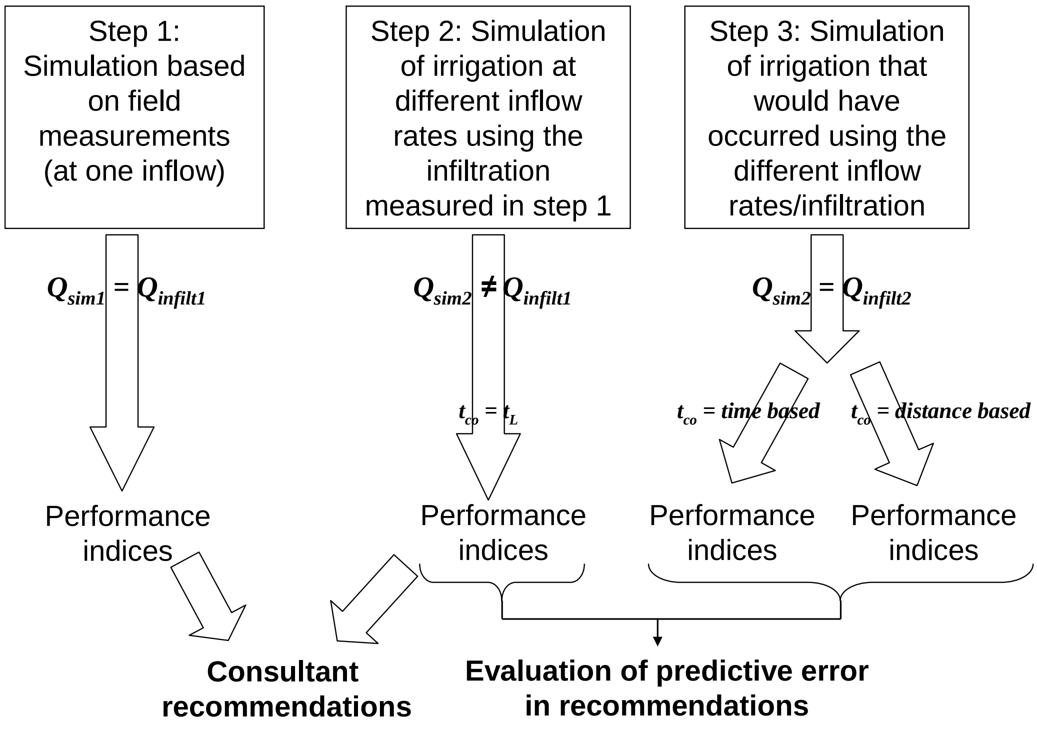

Figure 1: Framework for the evaluation of errors in irrigation performance prediction when the infiltration function is not adjusted in response to changes in inflow rate

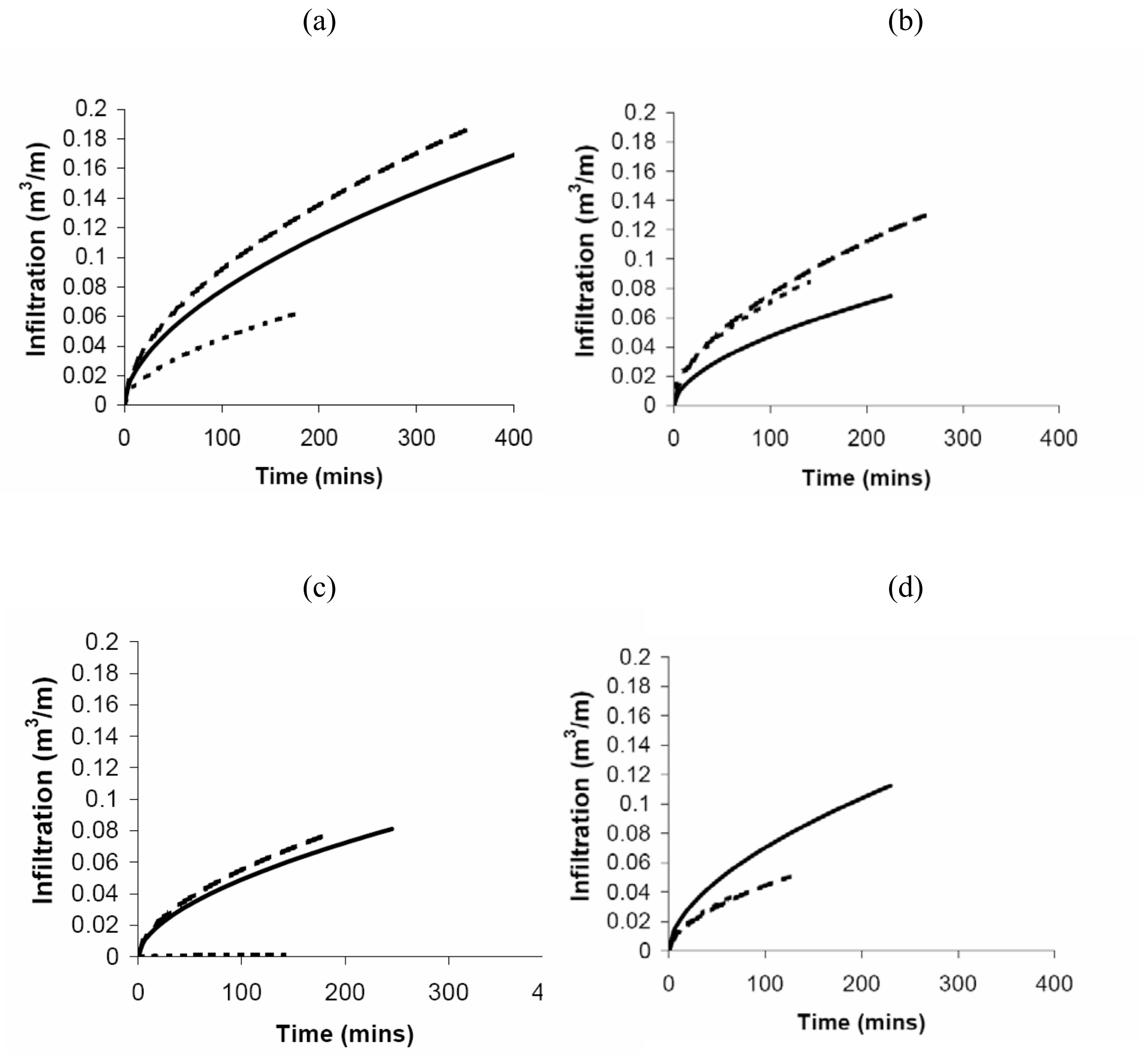

Figure 2: Scaled cumulative infiltration curves for the first irrigation of the season applied to field slopes of (a) 0.09 % (b) 0.13 % (c) 0.25 % and (d) 0.31 % where the inflow rate was 1.5 (—), 2.0 (– –) or 3.0 l s^{-1} (▪▪▪)

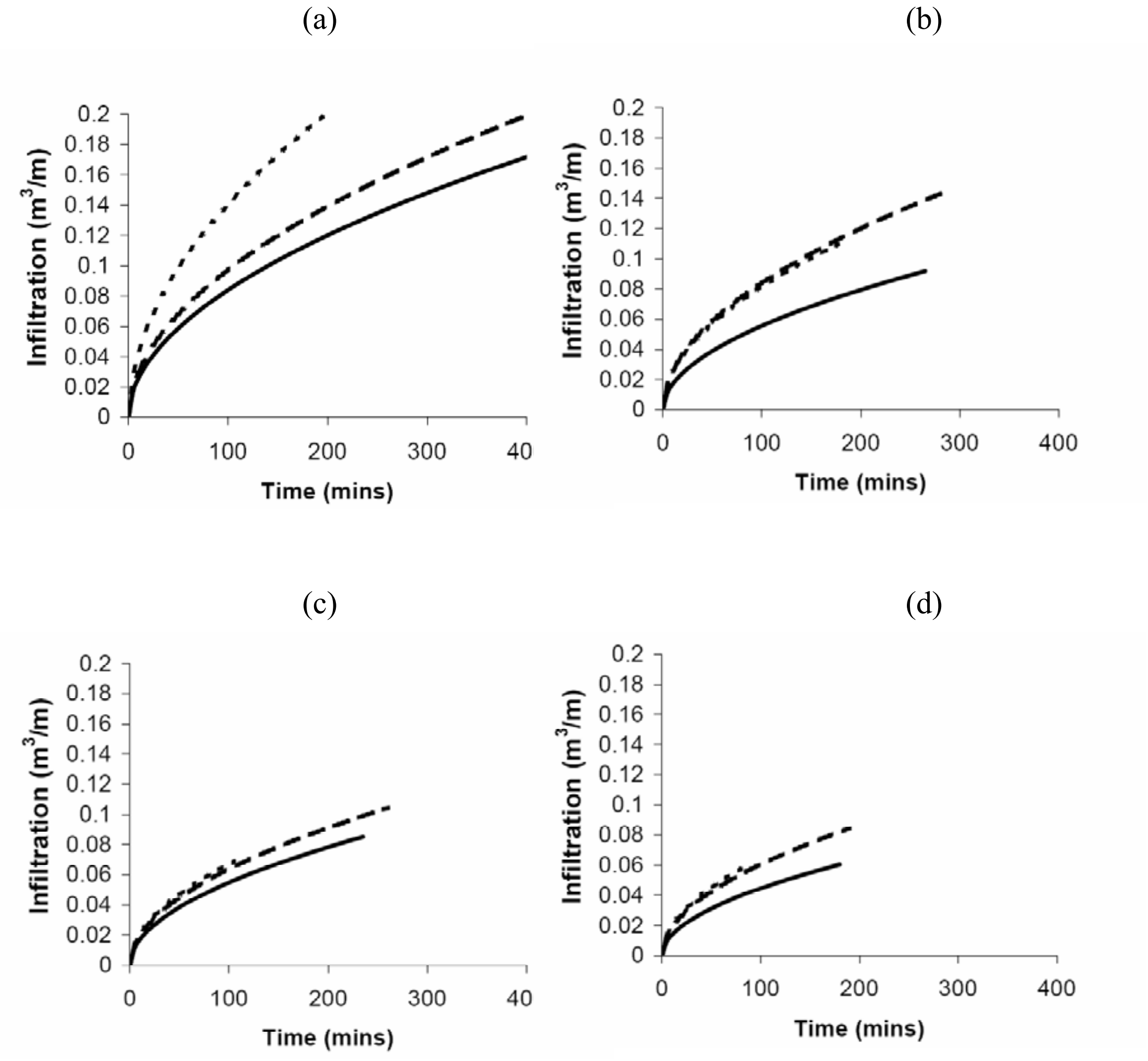

Figure 3: Scaled cumulative infiltration curves for the fifth irrigation of the season applied to field slopes of (a) 0.09 % (b) 0.13 % (c) 0.25 % and (d) 0.31 % where the inflow rate was 1.5 (—), 2.0 (– –) or 3.0 l s^{-1} (▪▪▪)

Table 1: Advance parameters for the measured irrigation events
(from Mwatha and Gichuki, 2000)

Irrigation	**Slope (%)**	**Inflow ($l\ s^{-1}$)**	**Advance parameters**		
			p	***r***	**t_L (mins)**
1	0.09	1.5	9.6	0.56	425
		2.0	11.8	0.54	362
		3.0	34.5	0.41	173
	0.13	1.5	16.2	0.53	223
		2.0	13.8	0.54	261
		3.0	21.3	0.52	146
	0.25	1.5	21.6	0.47	242
		2.0	23.3	0.48	185
		3.0	38.8	0.52	46
	0.31	1.5	4.1	0.78	231
		2.0	21.0	0.54	125
		3.0	15.7	0.70	63
5	0.09	1.5	12.7	0.49	572
		2.0	6.1	0.67	308
		3.0	10.2	0.57	345
	0.13	1.5	12.6	0.56	262
		2.0	11.3	0.57	290
		3.0	18.3	0.53	177
	0.25	1.5	13.5	0.56	231
		2.0	22.2	0.46	256
		3.0	16.2	0.61	110
	0.31	1.5	16.5	0.55	179
		2.0	17.9	0.53	186
		3.0	13.4	0.68	90

Table 2: Example of the effect of infiltration function and inflow rate on the accuracy of performance evaluations for the (a) first and (b) fifth irrigation event

				0.09 % slope				0.31 % slope			
					Performance indices (%)				Performance indices (%)		
Evaluation framework component	**Simulation strategy**	**Q_{sim} (L s-1)**	**Q_{infilt} (L s^{-1})**	**t_{co} (min)**	**E_a**	**E_r**	**DU**	**t_{co} (min)**	**E_a**	**E_r**	**DU**
(a)											
Step 1	$Q_{sim1} = Q_{infilt1}$ where $t_{co}= t_L$	1.5	1.5	526	39	100	63	421	48	99	63
Step 2	$Q_{sim2} \neq Q_{infilt1}$ where $t_{co}= t_L$	2	1.5	297	51	99	67	237	64	98	67
		3	1.5	145	69	99	75	116	85	96	75
Step 3	$Q_{sim2} = Q_{infilt2}$ where $t_{co} = t_{co}$ estimated in step 2 above	2	2	297	45	87	30	237	65	100	83
		3	3	145	65	93	95	116	72	82	93
	$Q_{sim2} = Q_{infilt2}$ where $t_{co} = t_L$	2	2	410	37	98	64	151	93	91	69
		3	3	78	86	66	88	64	90	57	84
(b)											
Step 1	$Q_{sim1} = Q_{infilt1}$ where $t_{co}= t_L$	1.5	1.5	529	39	100	64	166	99	80	73
Step 2	$Q_{sim2} \neq Q_{infilt1}$ where $t_{co}= t_L$	2	1.5	314	49	100	68	106	97	67	79
		3	1.5	161	63	100	75	62	88	54	86
Step 3	$Q_{sim2} = Q_{infilt2}$ where $t_{co} = t_{co}$ estimated in step 2 above	2	2	314	43	88	35	106	100	70	18
		3	3	161	42	66	0	62	100	70	33
	$Q_{sim2} = Q_{infilt2}$ where $t_{co} = t_L$	2	2	407	38	100	66	168	87	94	72
		3	3	379	27	100	65	98	89	95	80

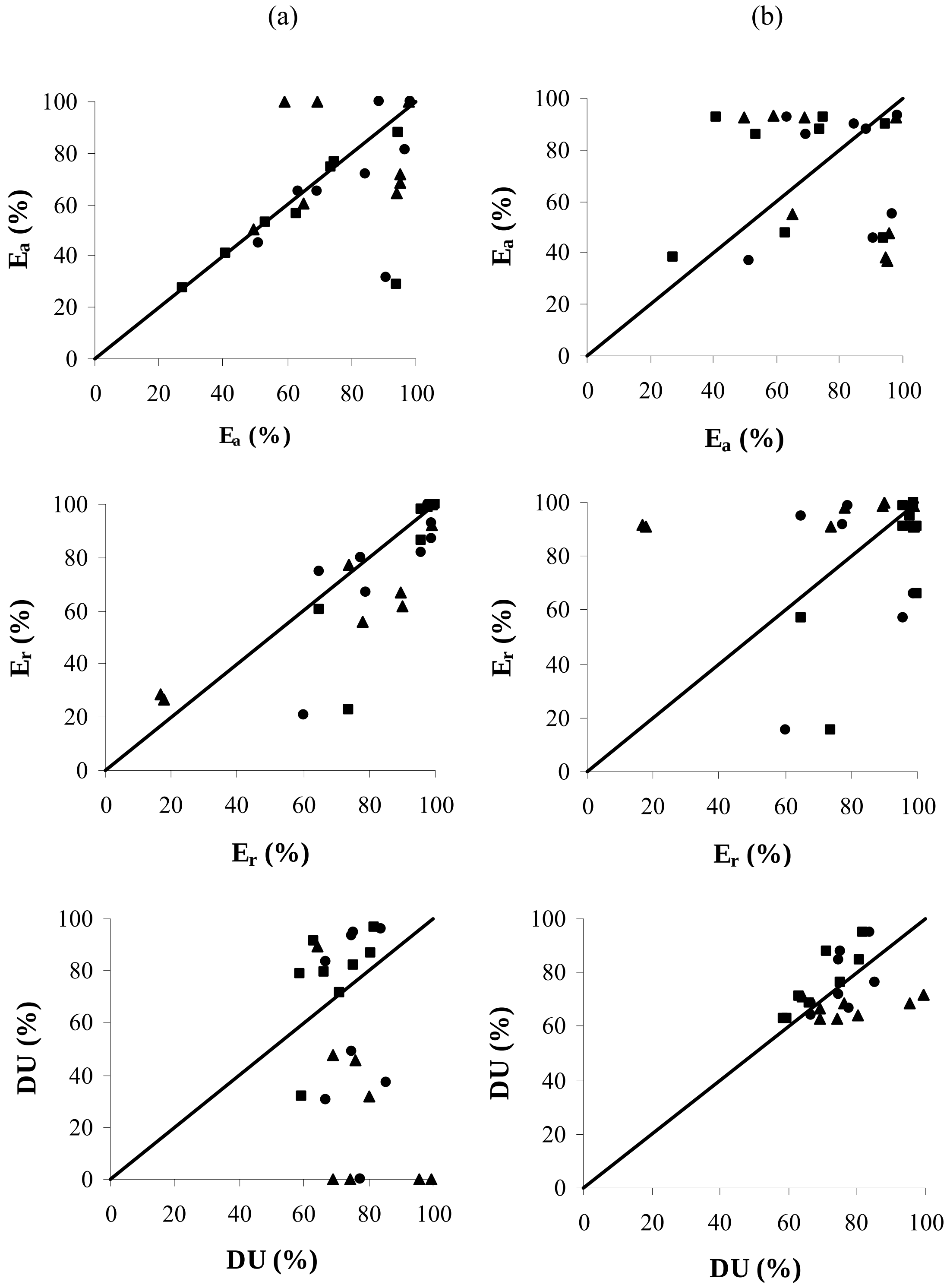

Figure 4: Effect of the inflow rate (● = 1.5; ■ = 2.0; ▲ = 3 L s^{-1}) at which the infiltration was estimated on accuracy of performance predictions for the first irrigation where recommendations for cut-off were specified by (a) time and (b) distance. The x-axis value was simulated with $Q_{sim2} = Q_{infilt1}$ and the y-axis was simulated with $Q_{sim2} = Q_{infilt2}$

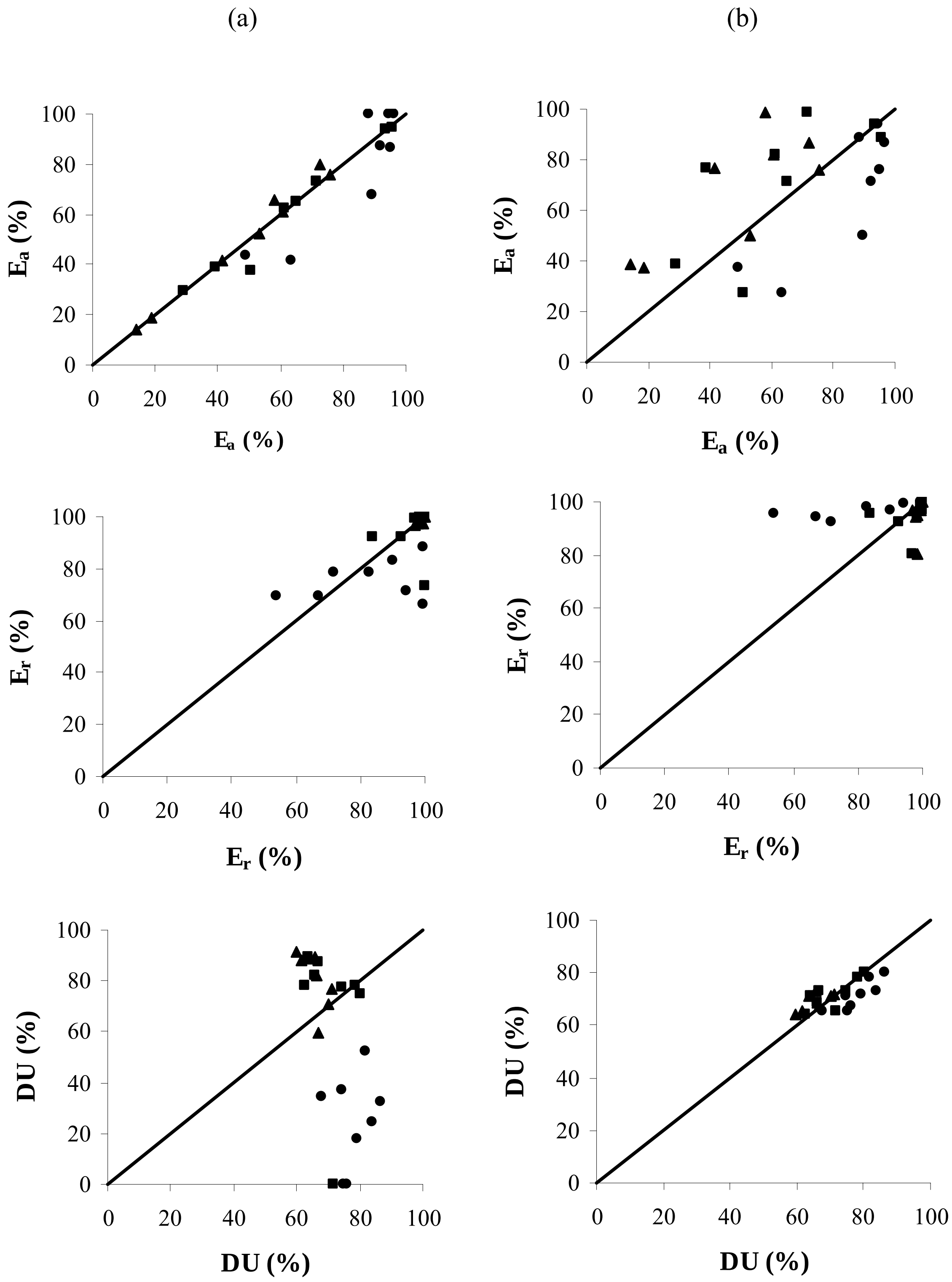

Figure 5: Effect of the inflow rate (● = 1.5; ■ = 2.0; ▲ = 3 L s^{-1}) at which the infiltration was estimated on accuracy of performance predictions for the fifth irrigation where recommendations for cut-off were specified by (a) time and (b) distance. The x-axis value was simulated with $Q_{sim2} = Q_{infilt1}$ and the y-axis was simulated with $Q_{sim2} = Q_{infilt2}$

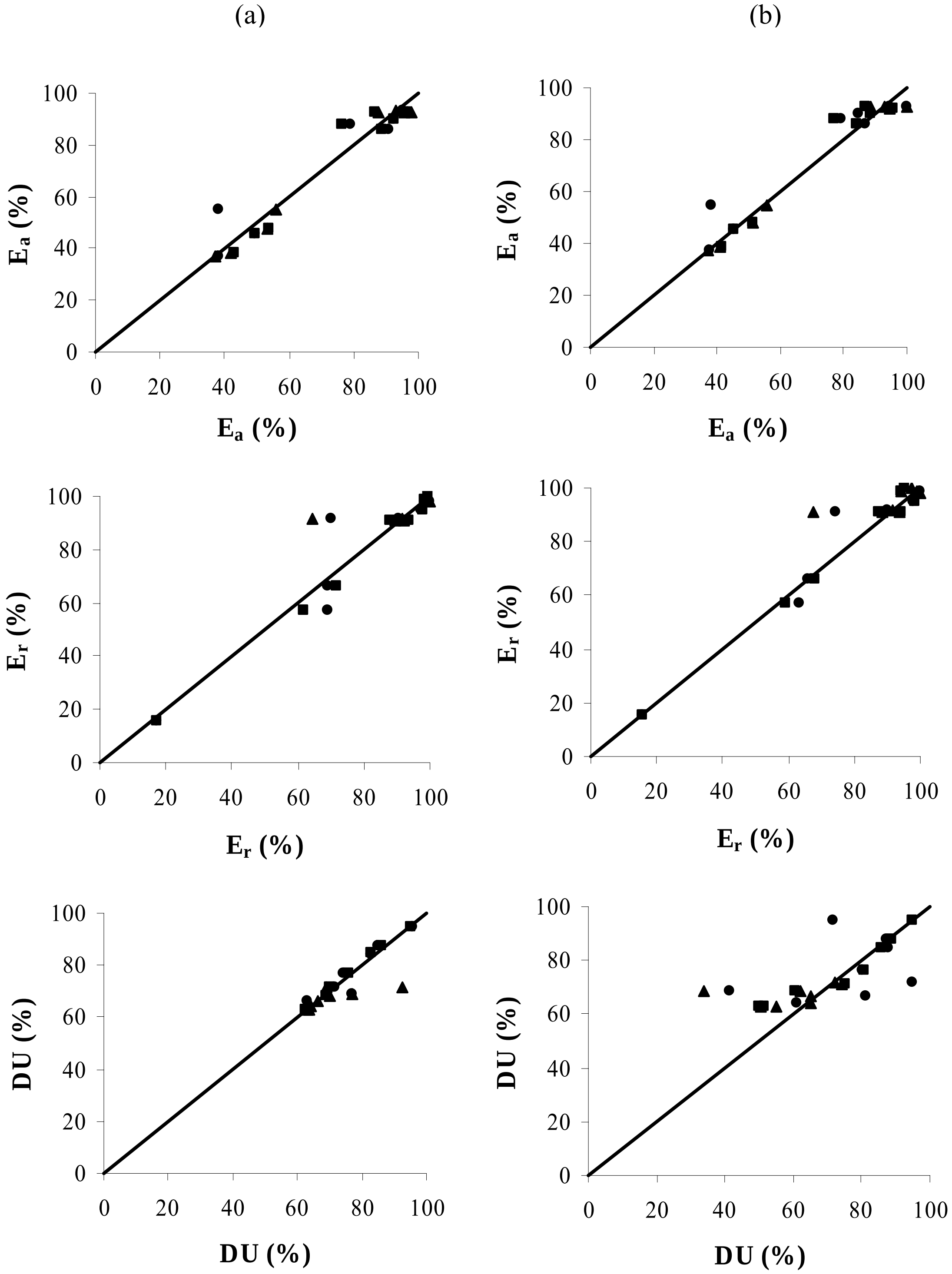

Figure 6: Effect of the inflow rate (● = 1.5; ■ = 2.0; ▲ = 3 L s^{-1}) at which the infiltration was estimated on accuracy of performance predictions for the first irrigation where recommendations for cut-off were specified by (a) time and (b) distance. The x-axis value was simulated with $Q_{sim2} = Q_{infilt1}$ where $Q_{infilt1}$ was adjusted for changes in wetted perimeter and the y-axis was simulated with $Q_{sim2} = Q_{infilt2}$

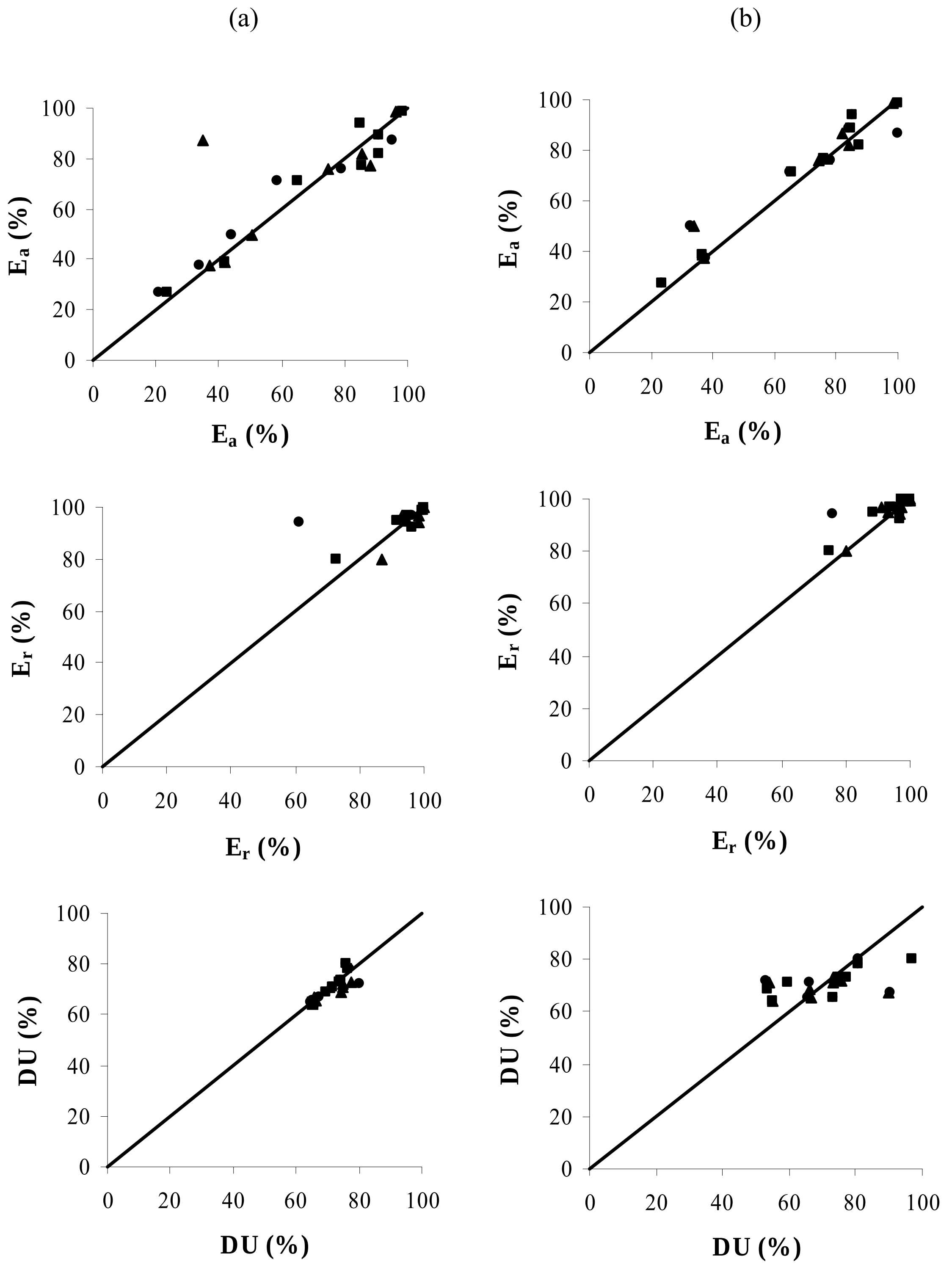

Figure 7: Effect of the inflow rate (● = 1.5; ■ = 2.0; ▲ = 3 L s^{-1}) at which the infiltration was estimated on accuracy of performance predictions for the fifth irrigation where recommendations for cut-off were specified by (a) time and (b) distance. The x-axis value was simulated with $Q_{sim2} = Q_{infilt1}$ where $Q_{infilt1}$ was adjusted for changes in wetted perimeter and the y-axis was simulated with $Q_{sim2} = Q_{infilt2}$