SCENARIO ANALYSIS: THE EFFECTS OF INFLOW HYDROGRAPH SHAPE ON FERTILIZER LOSSES

ANALYSE DE SCENARIO ; EFFETS DE LA FORME D'HYDROGRAMME SUR LES EPRTES D'ENGRAIS

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ABSTRACT

Fertilizers are widely applied to agricultural fields using surface fertigation. However, there are still no adequate guidelines for the proper design and management of surface fertigation. The proper management of surface fertigation is important because of low distribution uniformity of water in surface irrigation. The efficient application and distribution of water in furrow irrigation is highly dependent on parameters such as inflow rate and inflow hydrograph shape. In this study, some modified furrow inflow hydrograph shapes such as modified cutback and nonlinear reducing were introduced and evaluated under field conditions. A zero-inertia model was used for simulation of surface fertigation for different field slopes and furrow lengths. An automated device was designed to apply different furrow inflow hydrograph shapes to the furrows. The one dimensional advection-dispersion model of the overland water and solute flow was used to simulate furrow irrigation fertigation. The results showed that fertilizer loss due to runoff decreased 9.37% for modified cutback inflow hydrograph shape and decreased 33.19% for nonlinear reducing inflow hydrograph shape. The use of correct inflow hydrograph shape can significantly reduce fertilizer losses.

Key words: *Furrow irrigation, fertigation, inflow rate.*

RESUME

Les engrais sont largement appliqués dans les champs agricoles en utilisant la fertigation de surface. Cependant, il n'y a pas de directives adéquates pour la conception et la gestion de la fertigation de surface. La bonne gestion de la fertigation d'irrigation de surface est nécessaire

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en raison de l'uniformité inférieure de distribution d'eau en irrigation de surface. L'application et la distribution efficiente de l'eau en irrigation par sillons est fortement dépendante des paramètres tels que le taux d'entrée et de la forme d'hydrogramme d'entrée. Dans cette étude, ont été introduites et évaluées sur le terrain, certaines formes modifiées d'hydrogramme d'entrée de sillon telles que la réduction modifiée et non linéaire.

Un modèle d'inertie zéro a été utilisé pour simuler la fertigation de surface sur différentes pentes de terrain et longueurs de sillons. Un dispositif automatisé a été conçu pour appliquer différentes formes d'hydrogramme d'entrée de sillon. Le modèle unidimensionnel d'advection-dispersion de l'eau a été utilisé par voie terrestre et les courants pour simuler la fertigation de l'irrigation par sillons. Les résultats ont montré que la perte d'engrais en raison du ruissellement a diminué de 9,37% pour la forme réduite modifiée d'hydrogramme d'entrée, et a diminué de 33,19% pour la forme réduite non linéaire d'hydrogramme d'entrée. L'utilisation de la forme correcte d'hydrogramme d'entrée peut réduire de manière considérable les pertes d'engrais.

Mots clés : *Irrigation par sillon, fertigation, taux d'entrée.*

1. INTRODUCTION

Fertilizers are widely applied to agricultural fields using surface fertigation (application of fertilizers with irrigation water). However, there are still no adequate guidelines for the proper design and management of surface fertigation. The fertigation has certain advantages as compared to the conventional application of the fertilizer. They are reduction of fertilizer use, energy, labor, soil compaction, and machinery costs. Moreover, it allows growers to apply nutrients in small amounts throughout the season in response to crop needs without the possibility of crop damage or soil compaction caused by mechanized application methods (Abbasi et al. 2003b). Threadgill (1985) conducted a chemigation survey in the United States and found that while 61% of microirrigation and 43% of sprinkler irrigation systems used chemigation, only 3.5% of the surface irrigation systems utilized this technique. Likely reasons for the limited use of surface fertigation were the typically low uniformity of surface irrigation systems and fertilizer losses due to runoff (Threadhill et al., 1990). However, findings by Hanson et al. (1995) on 959 irrigation fields in California showed that the uniformity of border and furrow irrigation was generally higher than that for all other irrigation systems in the area. These findings indicate that further studies on surface fertigation are needed. Playan and Faci (1997) evaluated the uniformity of surface fertigation by conducting a series of field experiments on blocked-end borders. They also developed a fertigation model based on the one dimensional advection-dispertion equation to simulate the experimental data. The best fertigation uniformity was achieved by applying a constant fertigation rate during the entire irrigation event. Abbasi et al. (2003c) monitored two dimensional field-scale water flow and solute transport, and evaluated the effect of water level on transport and distributions of water and bromide in a field with blocked-end furrows under variable conditions. A positive correlation was found between water level and infiltrated amount of water or solute. Irrigation and solute application time increased with decreasing water level (Abbasi et al. 2003c).

The proper management of surface fertigation is important because of low distribution uniformity of water in surface irrigation. Regarding previous studies, furrow inflow rate and inflow hydrograph shape have high influence on infiltration equation. The efficient application and distribution of water in furrow irrigation is highly dependent on inflow hydrograph shape (Alazba, 1995; Bautista & Wallender, 1993; Trout & Kincaid, 1990). Correct selection of inflow hydrograph shape can decrease water and fertilizer losses. According to the above studies, to reduce fertilizer losses, it is necessary to study the effects of inflow hydrograph shapes on fertilizer losses due to runoff.

The objective of this study was to compare the fertilizer losses due to runoff for different field slopes and furrow lengths for constant and different modified furrow inflow hydrograph shapes.

2. MATERIALS AND METHODS

2.1 Solution techniques

2.1.1 Zero-inertia model

In zero-inertia model the deformable control volume approach is used. In deformable control volume approach there is a small slice of water flowing over the field and infiltrating into the soil. The small volume or cell is examined over a period of time. During this time step the flow into and out of the cell changes, thereby changing the cross sectional flow area at both the upstream and downstream boundaries of the cell. In addition, the depth of infiltration increases during the time step. In the deformable control volume approach the governing equations were discretized. The discretized equations were linearized by applying a Taylor series expansion according to Newton-Raphson procedure and then the algebraic linearized equations were solved using Gaussian elimination technique. More details about this model are given by Abbasi et al. (2003a). This model was written for the constant inflow hydrograph. In this study the model was extended to include different furrow inflow hydrograph shapes.

2.1.2 Multilevel calibration technique

The multilevel calibration technique was applied by walker in 2005 using hydrodynamic model (Walker, 2005) to estimate infiltration parameters and roughness coefficient in furrow irrigation. There are four characteristics such as the time of advance, the time of recession, the shape of the tail-water hydrograph and the magnitude of the tail-water hydrograph, which can be used to define intake and roughness parameters (K, a, f_0 and n). Each of the above four characteristics are sensitive to these four parameters with different level of sensitivity. For instance, the time of recession is relatively insensitive to the parameters a and K, the shape and magnitude of the tail-water hydrograph is primarily a function of a and f_0, and the advance time is somewhat more sensitive to a and K than f_0 or n. The required input data for multilevel calibration method are: furrow length, furrow cross section parameters, cutoff time, inflow and outflow hydrograph discharge, advance and recession time of the end of the furrow. In this method there is no need for advance or recession trajectories. This technique was used for estimation of Kostiakov - Lewis infiltration equation and roughness coefficient for different furrow inflow hydrograph shapes. More details about the multilevel calibration method are given by walker (2005) and Moravejalahkami et al. (2009).

2.1.3 Fertigation Model

Hydrodynamic dispersion and advection are the two most important processes governing solute transport during surface fertigation. Using the hypotheses of Holley (1971) that differential convective transport and turbulent diffusion processes may be combined in gradient diffusion terms, the 1D cross-sectional average dispersion equation for surface fertigation is as follows (Cunge et al. 1980; Abbasi et al. 2003b):

$$\frac{\partial (AC)}{\partial t} + \frac{\partial (AUC)}{\partial x} = \frac{\partial}{\partial x}\left(AK_x \frac{\partial C}{\partial x}\right) \quad (1)$$

Where *C* is cross-sectional average concentration, (kg/m^3); *U* is velocity (m/s); *A* is flow area, (m^2); K_x is dispersion coefficient, (m^2/s); *t* is time, (s) and *x* is space, (m).

The dispersion coefficient for overland flow can generally be described as follow (Abbasi et al. 2003b):

$$K_x = D_x u_x + D_d \quad (2)$$

Where D_x is longitudinal dispersivity, (m); u_x is overland flow velocity at location *x* (m/s) and D_d is molecular diffusion in free water.

Numerical solutions of the 1D advection-diffusion equation, subject to appropriate initial and boundary conditions, under conditions of overland flow require a great deal of care because of the dominance of the advection term in Eq. 1. A Crank-Nicholson finite difference scheme with a small truncation error of the order of $(\Delta x)^2 + (\Delta t)^2$ was used to numerically solve Eq. 1.

Two dimensionless numbers, the Peclet and Courant numbers, may be used to characterize the space and time discretizations for the fertigation model.

The mass of solute *Fz* (kg/m) infiltrated through the soil surface into the soil between two consecutive time steps can be estimated using the overland solute concentrations and infiltrated amount of water.

More details about the fertigation model are given by Abbasi et al. (2003b).

2.2 Models verification

An experimental field with the sandy loam soil texture located at Isfahan University of Technology, near Isfahan was used to collect field data. Isfahan (33°, 47' North and 51°, 35' East and elevation of about 1580 m above mean sea level) is located in the central part of Iran. The experimental field was irrigated for the first time with no plant. The soil and furrow characteristics for the experimental field are shown in Table 1.

Table 1. Soil and furrow characteristics for the experimental field

Mass initial soil moisture (%)	Furrow length (m)	Bulk density (g/cm^3)	Field slope (m/m)	Clay (%)	Silt (%)	Sand (%)
7.45	50	1.24	0.005	29.5	30.5	40

In this study, an automated device was designed as a management tool to apply the desired furrow inflow hydrograph shapes in order to reduce losses and have better distribution of water along the field. The tests started with non-erosive discharge that was delivered to each furrow. Inflow, outflow, advance and furrow geometry were measured.

Fertilizer based on KNO_3 component was injected at a constant rate during the entire irrigation event. The fertilizer concentration was 3.26 g/L.

The inflow rate was delivered and measured at each furrow separately. The monitored furrows were marked with stakes at 7-m intervals. Advance and recession times were recorded at those stations along the monitored furrows. The furrow geometry was measured after irrigation.

Three replications were used for each measurement and the applied volume of water and the injected fertilizer mass were the same for all of the inflow hydrograph shape treatments.

Overland water samples for analysis of fertilizer concentrations were taken at three different locations from the inlet. Water samples at the different stations were collected as soon as water reached a particular station. Samples were initially taken at 1 min with the sampling interval increased gradually to every 10 min. The samples were analyzed for fertilizer concentrations with steam distillation.

In this study, two modified furrow inflow hydrograph shapes such as modified cutback and nonlinear reducing were introduced. In the modified cutback inflow hydrograph shape, the inflow discharge is decreased after the completion of the advance phase (Figure 1) and in the nonlinear reducing inflow hydrograph shape; the inflow discharge starts to decrease from the beginning of irrigation in a sigma shape (Fig. 2). The modified zero- inertia model (Abbasi et al. 2003a) for the above inflow hydrograph shapes under different field slopes and furrow lengths applied.

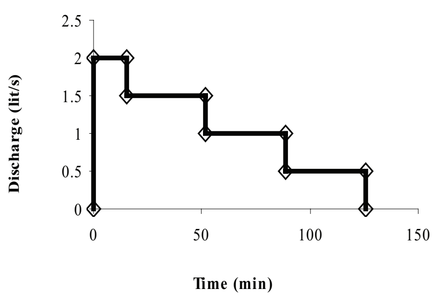


Fig. 1. Modified cutback inflow hydrograph shape

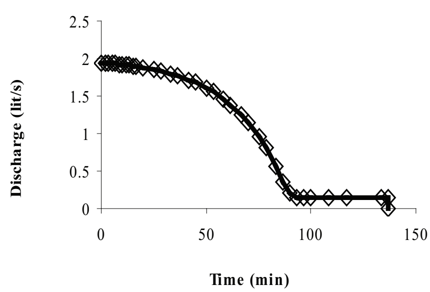


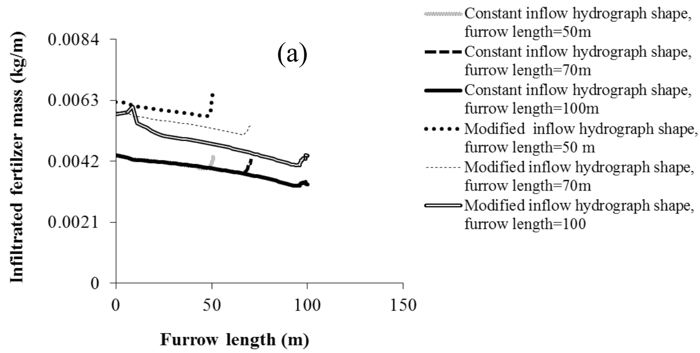
Fig. 2. Nonlinear reducing inflow hydrograph shape

3. RESULTS AND DISCUSSION

To evaluate surface fertigation in constant and modified furrow inflow hydrograph shapes, the surface fertigation model was run 2640 times for different treatments. The parameters of Kostiakov-Lewis and manning roughness coefficient were determined according to the field condition. The injected fertilizer mass was the same for all of the treatments. A sensitivity analysis showed that the longitudinal dispersivity (D_x) did not play an important role in surface fertigation and on the overland solute concentrations. So the dispersivity parameter was found to be 10 cm using model calibration. The same results were reported by Abbasi et al. (2003b).

In Figure 3 the fertilizer mass along the furrow were shown for the constant and the modified inflow hydrograph shapes for different furrow lengths. According to this figure as the furrow length increases the difference of fertilizer mass between constant and modified inflow hydrograph shapes decreases. These results show that the effect of modified inflow hydrograph shapes on decreasing fertilizer losses due to runoff is more significant for lower furrow lengths.

The fertilizer mass along the furrow were calculated for the constant, modified cutback and nonlinear reducing inflow hydrograph shapes for different field slopes which are not shown here. According to these results by increasing of the field slope the difference of fertilizer mass between the constant and the modified inflow hydrograph shape didn’t change.



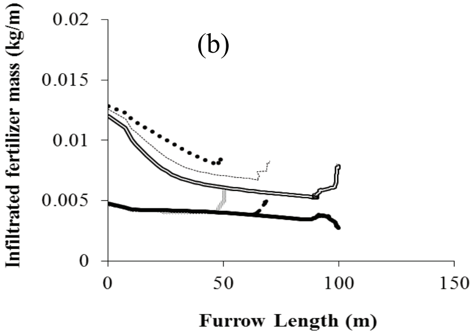


Fig. 3. Infiltrated fertilizer mass along the furrow (a=modified cutback inflow hydrograph shape, b=nonlinear reducing inflow hydrograph shape)

In Table 2 the fertilizer losses due to runoff are shown for the constant and the modified cutback inflow hydrograph shapes. Table 2 shows as the furrow length increases the difference in fertilizer losses due to runoff does not change significantly for the constant and the modified cutback inflow hydrograph shapes. However, the fertilizer loss due to runoff decreased nearly 10.27% for the modified cutback inflow hydrograph shape for different furrow lengths. The same results were found for the nonlinear reducing inflow hydrograph shapes. The fertilizer loss due to runoff was decreased 31.24% for nonlinear reducing inflow hydrograph shape.

Table 2. Fertilizer losses due to runoff for the constant and the modified cutback inflow hydrograph shape

Furrow length (m)	Fertilizer losses due to runoff (%)	
	Constant inflow hydrograph shape	Modified cutback inflow hydrograph shape
50	56.91	65.4
70	41.22	53.86
100	26.69	36.42

In Table 3 the fertilizer losses due to runoff are shown for the constant and the nonlinear reducing inflow hydrograph shapes. Table 3 shows that by increasing the field slope the difference in fertilizer losses due to runoff does not change significantly for the constant and the nonlinear reducing inflow hydrograph shapes. However the fertilizer loss due to runoff was decreased 35.13% for the nonlinear reducing inflow hydrograph shape. The same results were found for the modified cutback inflow hydrograph shape. The fertilizer loss due to runoff was decreased nearly 8.46% for the modified cutback inflow hydrograph shape for different field slopes.

Table 3. Fertilizer losses due to runoff for the constant and the nonlinear reducing inflow hydrograph shape

Filed slope (m)	Fertilizer losses due to runoff (%)	
	Constant inflow hydrograph shape	Nonlinear reducing inflow hydrograph shape
0.2	55	20.01
0.5	60.76	27.79
1	64.51	27.07

The evaluation of modified inflow hydrograph shapes under different field slopes and furrow lengths showed that the application of modified inflow hydrograph shapes can decrease fertilizer losses due to runoff and consequently water resourced pollution.

4. SUMMARY AND CONCLUSIONS

Furrow irrigation performance and overland solute concentration along the furrow are highly dependent on furrow inflow hydrograph shape. The results of this study showed to improve furrow irrigation performance and to reduce the fertilizer losses the proper inflow hydrograph shape can play a major role. An automated device was designed to apply different furrow inflow hydrograph shapes to the furrows. A zero-inertia model was modified to simulate furrow irrigation performance for different furrow inflow hydrograph shapes. The one dimensional advection-dispersion model of the overland water and solute flow was used to simulate furrow irrigation fertigation. The modified inflow hydrograph shapes reduced the tailwater runoff significantly at different field slopes and furrow lengths. The fertilizer loss due to runoff was decreased 9.37% for modified cutback inflow hydrograph shape. The fertilizer loss due to runoff was decreased 33.19% for nonlinear reducing inflow hydrograph shape. The use of correct inflow hydrograph shape can significantly reduce fertilizer losses and consequently water resource pollution.

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