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Research Paper

Calibration of infiltration, roughness and longitudinal dispersivity coefficients in furrow fertigation using inverse modelling with a genetic algorithm

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Determining soil hydraulic properties in surface irrigation which the soil surface is used both to convey and infiltrate water is very important. It becomes an issue of great concern when fertilisers were also added to irrigation water during fertigation. The purpose of this study was to estimate infiltration, roughness and longitudinal dispersivity coefficients in conventional and alternate furrow fertigation using inverse modelling with a genetic algorithm. A surface fertigation model was used to simulate overland water flow and solute transport. To discover optimum values of the coefficients, a genetic algorithm with fifteen objective functions were used to minimise the differences between observed and simulated values of advance time, recession time, runoff hydrograph and runoff nitrate concentration. The results indicated that the infiltration, roughness and fertiliser dispersivity parameters were more sensitive to runoff, recession time and runoff nitrate concentration, respectively. The best simulations of advance and recession phases were obtained by the coefficients which were estimated from objective function that minimised the differences between observed and simulated values of advance and recession time, respectively. For improving simulation of runoff discharge, minimising the differences between observed and simulated values of runoff hydrograph as well as advance time was necessary. Similarly, the improved simulation of runoff nitrate concentration needed minimising differences between simulated and measured values of both advance and runoff nitrate concentration. The proposed inverse modelling approach with GA resulted in better performance as compared to the two-point method, particularly in fixed and variable alternate furrow fertigation.

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1. Introduction

Surface irrigation is the oldest and most common irrigation method throughout the world although it traditionally suffers from many problems such as low efficiency and low uniformity (Gillies & Smith, 2005). Since in this method the soil surface is used both to convey and infiltrate water (Walker & Skogerboe, 1987), identification of the correct management requires the study of the complex interaction between irrigation water and soil. Therefore, a great obstacle in the improving surface irrigation performance is the difficulty of estimating the infiltration parameters (Bautista, Warrick, & Strelkoff, 2014; Elliott, Walker, & Skogerboe, 1983). In recent decades, surface fertigation has been identified as a technology to increase fertiliser distribution uniformity and application efficiency (Abbasi, Simunek, Van Genuchten, Feyen, & Adamsen, 2003; Ebrahimian, Keshavarz, Playán, 2014; Ebrahimian, Liaghat, Parsinejad, & Playán, 2012; Ebrahimian et al., 2013b; Perea, Strelkoff, Adamsen, Hunsaker, & Clemmens, 2010). Hence identifying soil characteristics in such fertigation systems which convey and infiltrate fertilisers as well as irrigation water became an issue of great concern. If the soil characteristics are estimated inaccurately, the design and management of these systems may be inappropriate, resulting in considerable damage to environment and ecosystem.

Determining infiltration parameters in situ is time consuming and expensive. Since infiltration properties exhibit temporal and spatial variability, many measurements are needed to explain average field conditions (Ebrahimian, Liaghat, Ghanbarian-Alavijeh, & Abbasi, 2010; Walker, 2005). Another way of determining infiltration and roughness parameters is to use advance, wetting and recession phases during an inverse solution approach. The two common methods for determining infiltration equation for furrow irrigation are the two-point method (Elliott & Walker, 1982) and infiltration optimisation (McClymont & Smith, 1996). Bautista, Clemmens, and Strelkoff (2009) mentioned that infiltration parameter estimation with the two-point method is inherently uncertain because of the limited infiltration information provided by the advance phase of the irrigation and the sensitivity of the calculations to uncertain advance phase data. The two-point and infiltration optimisation are both based on combining the modified Kostiakov equation and the volume balance model using advance data. The flaw in such schemes is that the soil behaviour may change during the irrigation. To better estimate infiltration coefficients, Gillies and Smith (2005) used both advance and runoff data with a simple volume balance approach. They concluded that the inclusion of runoff did not compromise the ability to reproduce the advance curve, but the simulations were more capable of reproducing the measured runoff rates and volumes and therefore offer better estimations of the total volume applied to the soil. Walker (2005) proposed the multilevel calibration technique to estimate both infiltration and roughness coefficients using inflow and runoff hydrographs. He showed that these coefficients led to accurate simulation of surface runoff and recession trajectory; however it lacked the same capacity to simulate the advance trajectory. Moravejalahkami, Mostafazadeh-Fard, Heidarpour, and Abbasi (2009) studied the ability of multilevel calibration to determine infiltration and roughness parameters in three different inflow hydrograph shapes i.e. constant, cablegation and cutback. The overall result proved that multilevel calibration could adequately predict the field data better than the two-point method.

During the last decade, several studies revealed that inverse modelling could effectively determine soil hydraulic properties (Hopmans & Simunek, 1999; Mohanty, 2013; Vrugt, Stauffer, Wöhling, Robinson, & Vesselinov, 2008). Inverse modelling is defined as the process of estimating model inputs by matching a forward model to measured data within an optimisation algorithm. The success of an inverse parameter determination depends on how well the mathematical problem can be posed. A problem is said to be ill-posed if it has either no solution at all, no unique solution, or the solution is unstable (Carrera & Neuman, 1986; Mao et al., 2013). The ill-posedness issue is generally due to lack of information on the problem, boundary conditions (Mao et al., 2013), type of optimisation algorithm (Vrugt, Bouten, Gupta, & Hopmans, 2003; Wöhling, Vrugt, & Barkle, 2008), the high correlation among hydraulic parameters (Hopmans, Šimunek, & Bristow, 2002) or low sensitivity of parameters (Van Dam, Stricker, Droogers, 1992). Abbasi, Simunek, Feyen, Van Genuchten, and Shouse (2003) simultaneously estimated soil hydraulic and solute transport parameters in furrow irrigation via inverse modelling. They revealed that agreement between model predictions and measured infiltration data was generally satisfactory. Wöhling et al. (2008) compared three multi-objective optimisation algorithms with laboratory analysis for determining soil hydraulic properties. They demonstrated substantial errors in laboratory analysis while all optimisation algorithms predicted soil hydraulic properties precisely.

Previous research has shown that optimised values from local optimisation algorithms, such as the Levenberg–Marquardt (Levenberg, 1944; Marquardt, 1963) and Simplex (Nelder & Mead, 1965), depend on the location from which these algorithms started. Therefore, they might not be appropriate for calibrating complex and highly nonlinear problems (Mertens, Kahl, Gottesbüren, & Vanderborght, 2009; Wöhling et al. 2008). However, the genetic algorithm method (Goldberg & Holland, 1988) searches the entire population instead of moving from one point to the next and can, therefore, overcome the limitations of traditional methods (Ines & Mohanty, 2008). Genetic algorithms have been successfully applied in the past decades for optimising design and management of irrigation systems for different purposes (Ebrahimian & Playán, 2014; Kuo, Merkley, Liu, 2000; Pais et al., 2010). The objective of this study is to apply an inverse modelling approach with the genetic algorithm to estimate the coefficients of the modified Kostiakov infiltration equation, Manning's roughness and longitudinal dispersivity for surface fertigation practice using field data including advance and recession times, runoff hydrograph and runoff nitrate concentrations.