# Simulating leaching of potassium in a sandy soil using simple and complex models

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### ABSTRACT

The objective of this study was to assess the applicability of the Burn's-type model (simple model) and LEACHM (complex model) for describing potassium ($K^+$) leaching in soil. Movement of $K^+$ in a sandy soil using leaching column was examined. Pulse of $K^+$ was applied to the column and then eluted with calcium chloride ($CaCl_2$) solutions of various concentrations (3–15 mM $CaCl_2$). Breakthrough curves for $K^+$ indicated that after the initial adsorption, the concentration of $K^+$ in the leachate would decrease rapidly with $K^+$ retained strongly, so giving an extended tail. The LEACHM model was able to predict approximately the extent of $K^+$ retardation, but $K^+$ was leached a little later than simulated particularly at 5, 10 and 15 mM calcium ($Ca^{2+}$) concentrations and the model was not able to predict effectively the slow rate of desorption of $K^+$ from the column. Simulations using Wineglass model, described the location of the peak only in some cases and underestimated tailing. Also, the pulse of $K^+$ was simulated to appear a little earlier and less tailed than that measured. Possible causes for the differences between the measured and simulated curves are as follows: the inability of the models to account for kinetically controlled chemical processes, assumption of a constant adsorption coefficient which is not valid as the adsorption coefficient changes as the concentration of $K^+$ and $Ca^{2+}$ changes during the leaching. The models could be useful tool to simulate leaching of $K^+$ from agricultural land in regions with low quality water for irrigation and to forecast information in decision-making for environmental management.

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## 1. Introduction

Low quality water is a common feature of arid and semiarid regions and is often used for irrigation in absence or limited availability of better quality waters (Gupta, 1979; Rhoades, 1992; Hamdy, 1996). Irrigation with water in which concentrations of major cations such as calcium ($Ca^{2+}$) are higher than in good quality water, leads to an increased potassium ($K^+$) desorption and leaching. Interest in solute displacement has increased substantially and it is one of the important issues in soil pollution phenomena. Many management problems in agriculture involve the transport and reactions of dissolved chemicals that either are native to the soil or are added accidentally or deliberately to the soil surface. The design of optimum pesticide and fertilizer application rates and timing involves developing procedures to maximize the effectiveness of these chemicals within the root zone while minimizing their movement below it.

Models can provide useful estimates of leaching and thus aid in the control of losses. In the case of fertilizers, modelling of the transport of cations can be useful for making decision about the rate and timing of application. The fate of the nutrient $K^+$ has received less attention than that of nitrogen and phosphorus. Simulating the movement of $K^+$ is important

because of its implication in relation to the efficiency of fertilizer use. An increase in the $K^+$ concentration can be expected in groundwater within infiltration areas with agricultural land use, as a consequence of $K^+$ leaching (Jalali, 2005a). Apart from the clay type and content, organic matter content and the amount of applied $K^+$ (Johnston et al., 1993), and drainage (Shepherd and Bennett, 1998), the leaching of $K^+$ is also dependent on the concentration of other cations, especially $Ca^{2+}$ in the soil solution (Jalali and Rowell, 2003). Movement of $K^+$ in soil is markedly affected by their extent of sorption by the soil. Chemical processes can influence sorption reaction, control the concentration of $K^+$ in solution and its movement through the soil profile. Adsorption coefficient is used to relate the amount of $K^+$ sorbed by the soil to that dissolved in the water. Retardation of $K^+$ is known to depend on its adsorption coefficient and this coefficient is decreased by an increase in $Ca^{2+}$ concentration in leaching solution (Jalali and Rowell, 2003). The increased rate of movement of $K^+$ with increased $Ca^{2+}$ concentrations is related to the increased capacity of $Ca^{2+}$ to displace $K^+$ from exchange sites into solution.

One of the early works dealing with the transport and interaction of two species is that of Lai and Jurinak (1972). They assumed equilibrium is attained in the exchange of two ions between the solution and soil surfaces and utilizes where the classical convective–dispersive equation (CDE) is applicable. The presence of various processes associated with solute movement requires more complex models to fully describe these processes. Therefore complex models are needed in order to fully describe their transport. In complex models several processes, for example cation exchange, complexation, adsorption, precipitation-dissolution, and competitive adsorption are considered. A few examples of such complex models include: FIESTA to describe $Ni^{2+}$ and $Cd^{2+}$ breakthrough curves in a sandy soil (Jennings et al., 1982) CHEMTRAN (Miller and Benson, 1983), and TRANQL (Cederberg et al., 1985) has been used by Valocchi et al. (1981) to describe $Ca^{2+}$ and $Mg^{2+}$ concentration, HYDROGEOCHEM for simulating transport of reactive multispecies chemicals (Yeh and Tripathi, 1991), and UNSATCHEM-2D for modelling major ion equilibrium and kinetic non-equilibrium chemistry in saturated soil (Simunek and Suarez, 1994).

In recent years, solute transport models, such as the Leaching Estimation and Chemistry Model (LEACHM; Hutson and Wagenet, 1992) have been used to evaluate the fate of contaminants in agricultural soils as basis to develop best management practices (Pennell et al., 1990; Soulsby and Reynolds, 1992; Jabro et al., 1993; Jalali, 1997; Paramasivam et al., 2002). This model is a one-dimensional model of water and solute movement, chemical reactions and transformations, and plant uptake in unsaturated zone. The model utilizes numerical solution techniques in which water flow is based on solution of Richard's equation and solute movement is based on solution of a CDE including sink and source terms. The LEACHM model is a deterministic mechanistic model which includes different processes involved in solute movement. In this model the adsorption coefficient is obtained from the Gapon equation which means both $K^+$ and $Ca^{2+}$ concentration are considered simultaneously.

Due to their complexity, several of these models have not been fully validated (Selim, 1992). There is a need for validating these models under different soil and environmental conditions (Addiscott and Wagenet, 1985). Here the LEACHM model has been used to simulate $K^+$ and $Ca^{2+}$ breakthrough curves and has been compared with a simple model.

## 2. Materials and methods

### 2.1. Soil

The soil sample was taken from the 0–30 cm layer of agricultural soil in Hamadan, western Iran. The soil was selected to represent the sandy loam and continuously cultivated for grape (*Vitis Vinifera* L.), typical of the region. The soil was air dried, crushed, and passed through a 2-mm mesh sieve before being stored in polyethylene bags. Some of the relevant chemical and physical properties of an air-dry <2 mm sample are as follows: pH 7.1; organic matter = 37 g $kg^{-1}$; cation exchange capacity = 12.6 cmol$_c$ $kg^{-1}$; clay = 157 g $kg^{-1}$; sand = 620 g $kg^{-1}$ and equivalent carbonate calcium = 47 g $kg^{-1}$. For column experiments, soil was saturated with $Ca^{2+}$ with a method similar to Jalali and Rowell (2003).

### 2.2. Column experiments

The leaching columns consisted of Pyrex tubes, 30 cm long, with an internal diameter of 4.8 cm. The soil was filled in columns to a height of 10 cm by uniform tapping to achieve uniform bulk density of 1.65 g $cm^{-3}$. During packing each soil was funneled into columns, while the walls were being simultaneously tapped with wood rod in order to achieve a uniform packing at the same bulk density. A whatman no. 42 filter paper was placed at the bottom of the leaching column. The bottom of the column was covered with nylon mesh. The column was initially saturated with distilled water. Each column was then leached with $CaCl_2$ solutions with varying concentrations (3, 5, 10, and 15 mM). The pore volume of the columns was taken to be 70 ml. Each leaching event consisted of collection of 3220 ml (equivalent to 1783 mm or 46 pore volumes) leachate.

### 2.3. Isotherm experiments

To determine $K^+$ sorption, 2.5 g soil was put into a 50 ml centrifuge tube with screw cap. Potassium sorption curves were obtained by shaking soil samples with solution of KCl containing 0, 1, 3, 5, 10, 15, 20, 30, 40, and 50 Mm $K^+$. The equilibrating solution was 3, 5, 10, and 15 mM $CaCl_2$ and the soil solution ratio was 1:10. The suspensions were shaken for 1 h. Sorbed $K^+$ was calculated from the difference between the concentration of soluble $K^+$ added in the initial solution and $K^+$ in the solution at equilibrium (Rowell, 1994). The procedure was performed in duplicate. The high dissolved $K^+$ concentrations used in the sorption experiments reflected the high concentration of water-soluble $K^+$ that occurs when $K^+$ pulse (10 ml of 50 mM KCl in different $CaCl_2$ solutions) is placed in the top of the column.