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THE SIMULATION MODEL OF SALT AND BORON TRANSPORT IN SURFACE SOIL

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ABSTRACT

A computer simulation leaching model was applied to a laboratory study of salt and boron leaching from fine and coarse texture soil. Leaching was performed by ponding of water with 5 cm head and by intermittent water application. Computer estimations on the transport of salt and boron in the both types of soil were compared with the measured changes in salt and boron concentrations during the leaching processes. The results indicated that the calculated values in EC and boron during the leaching process showed conformity particularly during the intermittent application. The boron reclamation needed four to five times more water than the salt reclamation.

Key Words: Salt, Boron, Leaching, Texture simulation model, Transport

TOPRAKLARDA TUZ VE BOR HAREKETİNİN SİMİLASYON MODELLEMESİ

ÖZET

Kaba ve ince bünyeli iki farklı toprakta laboratuvar denemesi kurularak bor ve tuz hareketi üzerine bilgisayar similasyon yıkama modeli uygulanmıştır. Denemede 5 cm göllendirme ve aralıklı sulama yöntemleriyle yıkama yapılmıştır. İki farklı toprakta yıkama esnasında belirlenen tuz ve bor konsantrasyonları bilgisayar program madeli ile tahmin edilen sonuçlarla kıyaslanmıştır. Elde edilen sonuçlara göre, yıkama işlemi süresince aralıklı sulama yöntemi uygulanmış topraklarda elde edilen EC ve bor değerleri bilgisayar program modeli ile tahmin edilen sonuçlarla uyum göstermiştir. Tuz yıkanmasına oranla bor yıkanması için 4-5 kat daha fazla su gerekmektedir.

Anahtar Kelimeler : Tuz, Bor, Yıkama, Bünye simulasyon modeli, Taşınma

1. INTRODUCTION

Various simulation models are available to describe solute leaching in soil. These models are differ in their approach and degree of complexity. There are a limited number of studies in the literature in which a simplistic model is used to determine the amount of water required to leach a given amount of salt from the soil. The examples of this kind of model are those of Bresler (1967), Terkeltoub and Babcock (1971), Burns (1972), Tanji et al., (1972), Pandey and Gupta (1978), Rose et al., (1982), Bond and Phillips (1990). In these models, rain or irrigation water is applied to the layer of soil causing a temporary increase in its water content. The incoming water and salts are assumed to be mix with water and salts already present in the layer. If the new water content of the layer exceeds field capacity, the surplus water and the salts it contains are transfered to the next layer where the procedure is repeated. Burns (1974) extended the model to include the effects of evaporation.

Addiscott (1977) developed a layer model in which the water in each layer is divided into mobile and immobile phases on the basis of the soil moisture characteristics. Rainfall causes piston flow in the mobile phase during which solute may move from one layer to the next. When the piston flow ceases, solute movement between the phases occurs to equalize the concentrations in the soil water between the phases.

Letfelaar and Sharma (1977) attempted to develop a numerical model under saturated flow conditions to describe salt release following the method of Terkeltoub and Babcock (1971). The numerical method is simply a salt balance equation.

Robbins (1979) developed a salt transport model by utilizing the modified plate theory as used by Terkeltoub and Babcock (1971). This comprehensive model (SALTFLO) was constructed by interfacing chemical precipitation-dissolution and cation exchange subroutines with an existing salt/water flow model.

Abbas (1984) developed a simplified solute transport model (SOLUT) based on the (SALTFLO) model of Robbins (1979). The simplification process involved the main salt /water flow routine as well as the chemistry and cation exchange subroutines in the chemistry subroutine. In developing the simplified salt-release model, the soil was assumed to be calcareous and may or may not contain gypsum. The free ion concentration in the soil was also assumed to be equal to the total analytical concentration. The Abbas's model was designed to estimate the boron concentration in percolating water under both saturated and unsaturated soil moisture flows. The adsorption-desorption reaction of boron was given by the Langmuir isotherm equation. The models were validated by comparing experimental and estimated values of leachate composition.

Al-Shammery (1987) studied the movement of salts in soil during leaching and determined the leaching norm using the computer model which was designed by Abbas (1984). The results indicated that the interfacing of a chemical and cation exchange subroutine with the main model was satisfactory in predicted both EC and ion concentration in the leached water for all treatments.

Omar (1994) used the SOLUT model of Abbas (1984) for tracing the salt concentration in gypsiferous soil with various saline and alkaline levels owing to the depth of columns of soil as a non-homogenous soil. The experimental data showed conformity of Na^+, Cl^- and other salt concentrations, with the model. In adition to these modeling approaches suggested for describing solute transport quantitatively such as a convection-dispersion equation (CDE) (Nielsen et al., 1986; Jacobsen et al., 1992; Costa et al., 1994 and Zhang, 1995).

They were also discussed with reference to their purpose, complexity, flexibility, transferability, usefulness for soil and compared and classified as far as possible within a framework that makes distinction between determinstic and stochastic, mechanistic and functional and rate and capacity models (reviewed by Addiscott and Wagenet, 1985; Jury et al., 1990; Ishiguro, 1991; Ishiguro, 1992; Jacobsen et al., 1992; Mansell et al., 1993).

Boron is an element essential for the growth of plants. The solution B concentration range where plants exhibit neither deficiency nor toxicity symptoms is narrow. There are a limited number of studies in the concerning boron leaching from soil. The soil texture and clay minerals play an important role on adsorption and movement of boron during the leaching process (Bingham and Page, 1971; Sparks, 1985; Goldberg and Glaubig, 1986; Sharma et al., 1989; Sözüdoğru et al., 1996; Goldberg et al., 1996).

Recently, computer simulation models have become a useful tool in understanding, predicting and solving environmental problems resulting from the movement of solute through soil. The purpose of this study were to investigate the salt and the boron movement during leaching in two soil textures which affected by different water flow rate and describes salt and boron ion leached, in uses a computer simulation model based on the simple-plate theory (Abbas, 1984), which accounts for chemical exchange and dissolution or precipitation of cations, and boron adsorption by the Langmuir equation. We also determined the effects of two methods of application of water to soil under saturated flow on the validity of the model in estimating salt and boron leaching and the amount of water required to reclaim salt and boron affected soil and finally, compared the transport of salt and boron in different conditions.

2. MATERIALS AND METHODS

2. 1. Materials

The soil samples used in this study were selected on the basis of texture. A clay loam, and a sandy loam were taken from a field of Ankara University

Agriculture land. The physical and chemical properties of these soil samples are shown in Tables 1 and 2.

Table 1. Physical Properties of Soils

Soil	Sand (%)	Silt (%)	Clay (%)	Texture	θsp ml.kg^{-1}	θfc ml.kg^{-1}	bd g.cm^{-3}
A	26.97	44.34	28.69	CL	517.50	309.10	1.17
B	65.76	19.50	15.07	SL	320.50	147.10	1.33

θsp: Saturation Percentage, θfc : Field capacity, bd : Bulk density
A : Fine texture, B : Coarse texture

Table 2. Chemical Properties of Soils Before Salinization

Soil	EC ext. mS cm^{-1}	pH ext.	Soluble ions (mg kg^{-1})						CEC Cmol kg^{-1}	Boron µg g^{-1}
			Ca^{++}	Mg^{+}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}		
A	1.60	7.80	320.00	316.16	19.32	88.75	1088.64	488.00	32.70	0.90
B	2.00	7.80	280.00	243.20	131.56	97.63	1533.12	244.00	18.99	0.60

A : Fine texture, B : Coarse texture

2. 2. Methods

A salinity treatment was added to the soils as a mixture of $CaCl_2$, $MgCl_2$, $NaCl_2$ and $MgSO_4$ in a water solution. H_3BO_3 was added as a separate solution of boric acid. The treated soils were dried and disturbed to columns having an inside diameter of 9.45 cm and a length of 20.5 cm. To achieve a uniform packing, the columns were filled with a previously standardized procedure. The chemical properties of the treated soils are shown in Table 3. All leaching treatments were done by using water which had an electrical conductivity (EC) 235 µS cm^{-1} and boron concentration of 0.1 µg ml^{-1}.

The first leaching treatment, a ponding method, consisted of addition of sufficient leaching water to produce and maintain a 5 cm head of water on the surface of the soil, for the interval of the treatment in the second treatment, an intermittent method, the leaching water was applied slowly and intermittently to prevent a head of water on the surface of the soil.

Table 3. Chemical Properties of Saline Soil Before Leaching Treatments

Soil	EC Ext. mS cm^{-1}	pH Ext.	Soluble ions (mg kg^{-1})						Exchangable Cations Cmol kg^{-1}			Boron µg g^{-1}
			Ca^{++}	Mg^{+}	Na^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	Ca^{++}	Mg^{++}	Na^{+}	
A	8.40	7.50	2504.40	997.12	310.73	22.29	9.27	0.90	22.29	9.27	0.40	6.60
B	13.50	7.40	2640.00	1723.56	813.05	10.59	6.94	0.70	10.59	6.94	0.70	9.60

A : Fine texture, B : Coarse texture

Chemical and physical properties of soil such as saturation percentage, field capacity, soil texture, chemical composition of cations and anions in the saturation extracts and leachate water, cation exchange capacity (CEC), exchangeable cations and electrical conductivity (EC) were determined (Richards, 1954 and Tüzüner, 1990). Boron determination was done using by Azomethine-H method (John et al., 1975).

2. 3. Theory of Transport Model

Description of the transport model used in this study is summarized here. The computer model includes a main program (MAIN) which describes salt/water transport through the soil layers during leaching and can be interfaced with a chemistry, cation exchange and boron subroutine (Abbas, 1984).

The approach used in the main salt balance program is as follows: A soil column is considered to be made up of n layers and these layers are assumed to be homogenous in bulk density, initial water content, and salt concentration. When the amount of water $(\theta_f - \theta_i)$ is applied to the first layer of soil, the resultant salt content in a unit soil volume;

$$C_{f1}\,\theta_{f1} = C_{i1}\,\theta_{i1} + C_{ir}\,(\theta_{f1} - \theta_{i1})$$

Where C_{f1} is the concentration at moisture content θ_{f1} in the first layer.

θ_i : is the initial and θ_f is the final mass water content in the layer of soil.

C_{ir} : is the salt concentration of applied water (mol l^{-1}), to the first layer of soil in which θ_{i1} is already present at salt concentration C_{i1}. .

The salt concentration leached to the second soil layer $C_{ir\ 1}$ with the water

(θ_{f1} - θ_{i1}) is:
$C_{ir\ 1} = C_{f1}$ fe

Where fe is a salt movement efficiency factor. Whose value depends on soil texture and has the value 1≥fe> 0.

The amount of salt retained in the first layer after drainage of (θ_{f1} -θ_{i1}) to 2 nd layer and the concentration of salt in 2 nd layer after complete mixing was calculated by the same process. The process is repeated for n layers.

In the chemistry subroutine the precipitation or dissolution of the lime was estimated from the ionic strength in any given layer and thermodynamic equilibrium constant for the dissolution of $CaCO_3$.

The cation exchange subroutine for calculating the exchangeable Ca, Mg and Na used the Gapon cation exchange equation as used by Richards (1954) in order to calculate the Gapon selectivity coefficient Kg (moll^{-1})$^{-1/2}$. The distribution of Ca and Mg between the soil solution and exchange complex by estimating the selectivity coefficient ($K_{Ca\text{-}Mg}$) for Ca-Mg exchange for each individual soil using the method of Oster and Frenkel (1980).

The solution leaving the n th layer as drainage will have its EC estimated by the following (Mc Neal et al., 1970):

$EC = K_0 C^b$

Where ;

C: is the ion concentration meq l^{-1} .
K_0 and b: are the published cofficients for each of the ionic species in solution.

The Langmuir adsorption isotherm equation was used in the boron subroutine for estimating sorption-desorption and the movement of boron in soil columns during moisture movement.

The input data required for applying the computer model are: the concentration of the ions in the irrigation water and the saturation extract (Ca, Na, Mg, HCO_3, Cl, and SO_4) all in mmol l^{-1}, B (mg l^{-1}), the cation exchange capacity (CEC) meq. 100 gr^{-1} , θ_{sp}, θ_{fc}, the moisture content during leaching (θ_m), bd bulk density gm.(cm^3)$^{-1}$ and the Kg for Na/(Ca+Mg) exchange and ($K_{Ca\text{-}Mg}$) for Ca/Mg exchange. In order to apply the model properly, columns were assumed to have 40 soil layers of 5 mm as described by Al-Shammary (1987).

3. RESULTS AND DISCUSSION

The Gapon selectivity coefficient (Kg) was calculated to be 0.2115 for soil A and 0.2963 for soil B. The ($K_{Ca\text{-}Mg}$) found was 0.6351 and 0.6103 respectively. In the ponding treatment, leaching efficiency (fe) was as 0.88 and 0.70 for soil A and soil B respectively. In the short interval treatment leaching efficiency was found to be 0.93 and 0.76 respectively. The amount of leachate is given as the ratio of depth of water applied (Dw) cm to the depth of the soil in the column (Ds) cm.

3. 1. Reclamation of saline soil

In order to decrease the salt concentration below 0.5 mS cm^{-1} , the amount of leaching water used for soil A was 17.1 cm, while this value was 17.96 cm for soil B after the ponding treatment. However, after the intermittent treatment, the values for soil A and B were 14.1 cm and 14.25 cm respectively.

Neither application method gave a significant difference between the soil A and B in the amount of the leaching water needed. However, due to the higher EC of the coarse soil B than fine soil A before leaching, there was a difference between the salt contents of soil A and B. The leaching efficiency was less in coarse textured soil as the macropores were dominant in the coarse textured soil and the water flow was primarily through the macropores, bypassing a large portion of the homogenous soil matrix (Bouma and Anderson, 1977; Jacobsen et al., 1992).

The leaching activity by the intermittent method was much more effective for soils A and B (18 % and 21 % respectively) than by ponding. Miller et al., (1965) emphasized that the leaching activity could reach 30 %, meaning that intermittent applications are more effective. Miller et al., (1965), Keller and Alfaro (1966) and Bresler and Hanks (1969), emphasized that at lower rates of water applications and lower degrees of soil saturation, the higher the amounts of salt that can be leached with one unit of water.

Experimental values obtained on salt movement were compared with the results from the computer model. The measured and calculated values for the ponded leaching are shown in Figure 1.

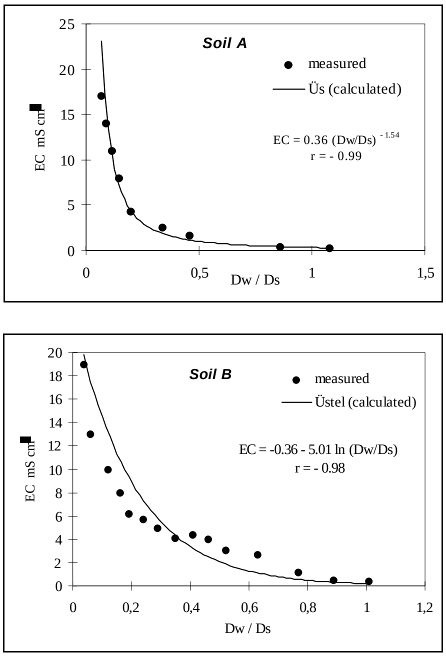

Figure 1. Measured and calculated EC values in soil A and B for the ponding treatment

Evaluation by curve-fitting is more suitable for soil A than for soil B. For the intermittent leaching system curve fitting estimates were more accurate for soils A and B than was found in the ponded leaching system (Figure 2).

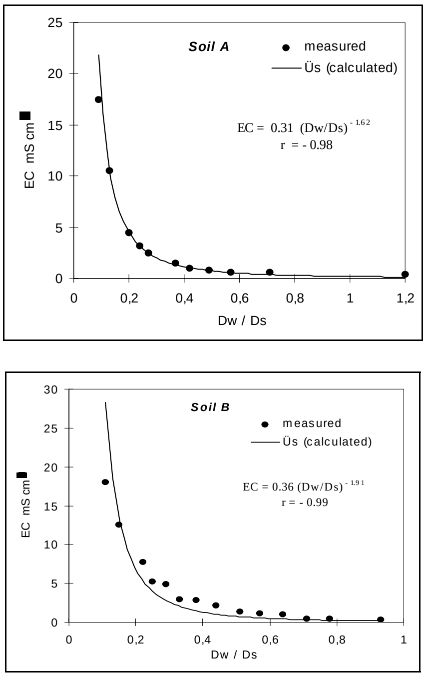

Figure 2. Measured and calculated EC values in soil A and B for the intermittent treatment

The calculated leaching values obtained for the ponded leaching of soil A was close to the measured values by only 52 %; while the calculated leaching value was 60 % for soil B. However this ratio was 60 % for soil A and 62 % (These values were calculated as:

$$\frac{\text{calculated water amount for leaching salt}}{\text{measured water amount for leaching salt}} \text{ x100)}$$

for soil B in intermittent leaching. The difference between the calculated values from the model and the measured value may be due to neglecting factor such as diffusion, hydrodynamic dispersion, moisture flow rates and ion pair formation in the computer model (Omar, 1994).

3. 2. Reclamation Of Boron Soils

The boron movement in soils was evaluated using the Langmuir Adsorption Isotherm. The adsorption studies showed that the adsorption maximum for the fine textured soil A was 25.65 µg B gr-1 soil and boron constant was 0.0731 whereas the coarse textured soil B had an adsorption maximum of 12.78 µg B gr-1 soil and boron constant was 0.057. The texture effect on the adsorption of boron by soils in this study is similar to that found by Abbas (1984); Sözüdoğru et al., (1996).

The ponded leaching on soil A used 100.61 cm leaching water to decrease the boron content below 0.5 µg ml-1. However the soil B required only 75.39 cm. With the intermittent system the amount of water required in soils A and B was 79.39 cm and 58.25 cm respectively. This is because of the soil texture, which has an important effect on boron movement during the leaching process. Boron movement was faster in coarse texture soils than in fine texture soils (Kubota et al., 1948, Goldberg and Glaubig, 1986).

The boron leaching activity was 22 % for soil A and 23 % for soil B.

The measured values from the boron leaching experiment were compared with the ones obtained as calculated data from the computer model. The measured and calculated values for both soil samples for both leaching systems are shown in Figure 3 and 4. The curve fitting results show that the estimates for the intermittent leaching are best for both soil samples. For the ponded leaching, the calculated values of the amount of leaching water compared to the measured values are 60 % for soil A and 53 % for soil B, while the same values for the intermittent application were 71 % and 58 % respectively.

The large difference between the calculated and measured values indicates that boron desorption values are needed with the model (Sharma et al., 1989).

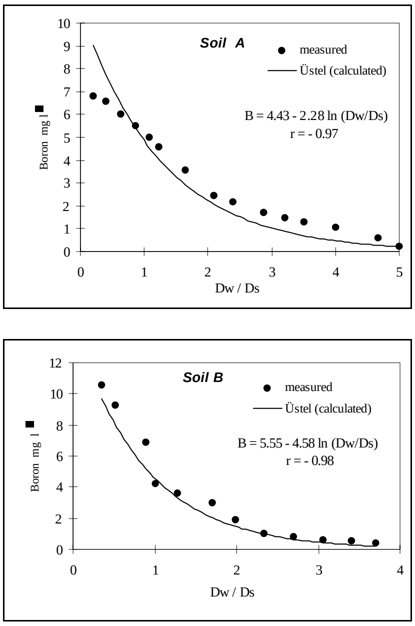

Figure 3. Measured and calculated concentration of Boron in soil A and soil B for the ponding treatment

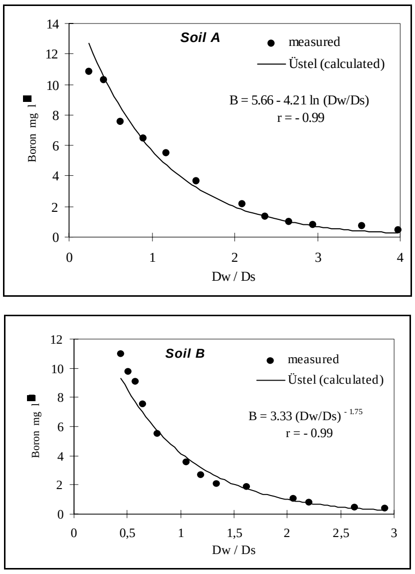

Figure 4. Measured and calculated concentration of Boron in soil A and soil B for the intermittent treatment

The comparison of the leaching of salt with that of boron shows that four to five times more water is needed for the boron. Boron is adsorbed by the colloid surface of the soil and leaches less readily than common salts (Alawi and Hammadi 1980; Shani and Hanks, 1993). In general, the model is satisfactory in estimating the leaching of salt and boron for both soil samples, particularly when compared to the intermittent leaching system.

4. REFERENCES

Abbas, F. M. 1984. A simplified Model for Salt and Boron Transport in Soils. Ph.D. Thesis. Utah University, Logan. USA.

Addiscott, T. M. 1977. A Simple Computer Model For Leaching in Saturated Soil. Journal of Soil Science. **(**28), 554-563.

Addiscott, T. M. and Wagenet, R. J. 1985. Concepts of Solute Leaching in Soils : A Review of Modelling Approaches. Journal of Soil Science, (36), 411-424.

Alawi, B. J. and Hammadi, K. B. ed. 1980. Land Reclamation. Bulletin of Mosoul University, Iraq.

Al-Shammary, S. L. A. 1987. Using of a Mathematical's Models to Study Salts Movement in Soil During Leaching. Msc. Master Thesis. Baghdad University. Agriculture Faculty, Iraq.

Bingham, F. T. and Page, A. L. 1971. Specific Character of Boron Adsorption by an Amorphous Soil. Soil Science Society of America Proceedings. (35), 892-893.

Bond, W. J. and I. R. Phillps, 1990. Ion Transport During Unsteady Water Flow in an Unsaturated Clay Soil. Soil Sci. Soc. Am. J. (54), 636-645.

Bouma, J. and Anderson, J. L. 1977. Water and Chloride Movement Through Soil Columns Simulating Pedal Soils. Soil Science Society of America Journal, (41), 766-770.

Bresler, E. 1967. A Model for Tracing Salt Distribution in the Soil Profile and Estimating the Efficient Combination of Water Quality on Quantity Under Varying Field Conditions. Soil Science, (104) 227-233.

Bresler, E. and Hanks, R. J. 1969. Numerical Method for Estimating Simultaneous Flow of Water and Salt in Unsaturated Soils. Soil Science Society of America Proceedings, (33), 827-832.

Burns, I. G. 1972. Leaching Studies. Report of the National Vegetable Researh Station for 1971. pp. 39-40. (Cited to Addiscott and Wagenet. 1985. Journal of Soil Science, (36), 411-424.

Burns, I. G. 1974. A Model for Predicting the Redistribution of Salts Applied to Fallow Soils After Excess Rainfall Or Evaporation. Journal of Soil Science (25), 165-178.

Costa, J. L., Knighton R. E and Prunty, L. 1994. Model Comparsion of Unsaturated Steady-Sate Solute Transport in a Field Plot. Soil Sci. Soc. Am. J. (58), 1277-1287.

Goldberg, S., and Glaubig, R. A. 1986. Boron Adsorption and Silicon Release by Clay Minerals Kaolinite, Montmorillonite, and Illite. Soil Science Society America Journal. (50), 1442-1448.

Goldberg, S., Forster, H. S., Lesch S. M and Heick, E. L. 1996. Influence of Anion Competition on Boron Adsorption by Clays and Soils. Soil Science, 161 (2), 99-103.

Ishiguro, M., 1991. Solute Transport Through Hard Pans of Paddy Fields: 1. Effects of Vertical Tubular Proes Made by Rice Roots on Solute Transport. Soil Sci. (152), 432-439.

Ishiguro, M., 1992. Solute Transport Through Hard Pans of Paddy Fields: 2. Cation Exchange Processes. Soil Science, 153 (1), 42-47.

Jacobsen, O. H., Leij F. J. and Van Genuchten, M. 1992. Lysimeter Study of Anion Transport During Steady Flow Through Layered Coarse-Textured Soil Profiles. Soil Science. 154 (3),196-205.

John, M. K., Chuah, H. H. and Neufeld. J. H. 1975. Application of Improved Azomethine-H Method to the Determination of Boron in Soils and Plants. Analytical Letters, (8), 559-568.

Jury, W. A., Dyson J. S. and Butters, G. L. 1990. Transfer Function Model of Field-Scale Solute Transport Under Transient Water Flow. Soil Sci. Soc. Am. J. (54), 327-332.

Keller, J., and Alfaro, J. F. 1966. Effect of Water Application Rate on Leaching. Soil Science, 102 (1971), 107-114.

Kubota, J. K., Berger C. and Troug, E. 1948. Boron Movement in Soils. Soil Science Society America Proceedings, (13), 130-134.

Letfelaar, P. A., and. Sharma, R. P. 1977. Leaching of a Highly Saline Sodic Soil. Journal of Hydrology, (32), 203-218.

Mansell, R. S., Bond, W.J. and Bloom, S. A. 1993. Simulating Cation Transport During Water Flow in Soil: Two Approaches. Soil Sci. Soc. Am. J. (57), 3-9.

McNeal, B. L., Oster J. D. and Hatcher, J. T. 1970. Calculation of Electrical Conductivity From Solution Composition Data as an Aid to in Situ Estimation of Soil Salinity. Soil Science, (110), 405-414.

Miller, R. J., Biggar J. W. and Nielsen. D. R. 1965. Chloride Displacement in Panoche Clay Loam in Relation to Water Movement and Distribution. Water Resource Research, (1), 63-73.

Nielsen, D. R., Genuchten M. Van and Biggar, J. W. 1986. Water Flow and Solute Transport Processes in the Unsaturated Zone. Water Resource and Research, (22), 895-1085.

Omar, S. M. 1994. Simulation Model and Programming of Ion Transport in Saline-Alkali Soils. Ph. D. Thesis. Ankara University, Soil Science Department, Ankara, Turkey.

Oster, J. D. and Frenkel H. 1980. The Chemistry of the Reclamation of Sodic Soil With Gypsum and Lime. Soil Science Society America Journal, (44), 41-45.

Pandey, R. N. and Gupta, S. K. 1978. Equation to Predict Leaching of Solute Salts in Saline Soils. Journal of Agricultural Science. Cambridge, (91), 131-134.

Richards, L. A., ed. 1954. Diagnosis and Improvement of Saline and Alkali Soils, USDA Agricultural Handbook No: 60.

Robbins, C. W. 1979. A Salt Transport and Storage Model for Calcareous Soil that May Contain Gypsum. Ph.D. Thesis. Utah State University, Logan (Cited to Abbas, 1984).

Rose, C. W., Chischester, F. W. Williams J. R. and Ritchie, J. T. 1982. A Contribution to Simplified Models of Field Solute Transport. Journal of Environmental Quality, (11), 146-150.

Shani, V. and Hanks, R. J. 1993. Model of Integrated Effects of Boron, Inert Salt, and Water Flow on Crop Yield. Agronomy Journal, 85 (1972), 713-717.

Sharma, H. C., Pasricha N. S. and Bajwa, M. S. 1989. Comparison of Mathematical Models to Describe Boron Desorption From Salt Affected Soils. Soil Sci. 147 (2), 79-84.

Sözüdoğru, S., Omar, S. M. and Usta, S. 1996. Boron Adsorption in Soils. Journal of Agricultural Sciences (in Turkish). 2 (1), 19-22.

Sparks, D. L. 1985. Kinetics of Ionic Reactions in Clay Minerals and Soils. Adv. Agron. (35), 231-266.

Tanji, K. K., Doneen, L. D. Ferry G. V. and Ayers. R. S. 1972. Computer Simulation Analysis on Reclamation of Salt-Affected Soils in San Joaquin Valley, California. Soil Science Society America Proceedings, (36), 127-133.

Terkeltoub, R.W. and Babcock, K. L. 1971. A Simple Method for Predicting Salt Movement Through Soil. Soil Science, (111), 182-187.

Tüzüner, A. 1990 ed. Soil and Water Analysises in Laboratory. Handbook Ministry of Agriculture, Turkey (in Turkish).

Zhang, R. 1995. Prediction of Solute Transport Using a Transfer Function Model and the Convection-Ispersion Equation. Soil Science 160 (1), 18-27.