UNIVERSITI PUTRA MALAYSIA

EFFECTS OF WATER TABLE MANAGEMENT PRACTICES ON THE TRANSPORT OF NITRATES IN SANDY UNDERGROUND ENVIRONMENT

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By

ABDUL HAKIM MASAUD MUSSA ALMDNY

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Dedicated to

My Parents, Wife, Daughter, and Son

Abstract of dissertation presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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July 2003

Chairman: Professor Salim Said, Ph.D.

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Enhancing the degradation of agrochemical pollutants by managing the water table has introduced a new horizon in agricultural pollution control. Experimental work in this area shows that the degradation of agrochemicals such as nitrate is dependent on the soil water content. The aim of this study was to evaluate the effect of water table fluctuations on the nitrate and chloride transport. A set of laboratory column experiments was conducted to investigate the transport of two non-sorptive chemicals nitrate and chloride (NO_3, Cl) to underground environment as effected by water table fluctuation. Three-controlled water table depths set at 0.25 m, 0.50 m, 0.75 m from the surface and free drainage treatment were used. The concentration curves for nitrate measured at different water table depths were not similar. The difference in the mean and the peak nitrate concentrations indicates highly significant difference in nitrate concentration among the water table depths. Through the values of mean and peak nitrate concentrations, the 0.25 m and 0.50 m water table depths gave the lowest mean and peak nitrate concentrations compared to the free drainage water table treatment. Descriptive statistical analysis indicates that there was highly

significant difference in the mean and the peak nitrate concentrations among the water table treatments. These results suggest that the saturation conditions associated with high water table will cause more nitrate degradation. The concentration curves for chloride measured at difference water table depths were similar, with slight difference in terms of peak and mean. The average chloride recovery rate was approximately 91% in all water table treatments. The results suggest that the chloride was not subjected to degradation and can be used as a good conservative tracer for nitrate transport. Comparison between nitrate and chloride concentrations among water table depths leads to the conclusion that water table depth was an important factor effecting nitrate transport. Based on the data from this experiment, nitrate has linear relation with chloride, and can be expressed as $NO_3 = k_c\, Cl$. The coefficient of linear relation, k_c is affected by water table depth. Statistical model (R^2 =0.83%) to simulate reduction and transport of nitrate as effected by different water table depths was established and fitted to the experimental data. The simulation results show reasonable agreement between predicted and measured data. These results revealed that water table level was an important factor affecting chemical transport. Anaerobic conditions associated with saturation condition have created the potential for more degradation and promote biological and chemical degradation to reduce nitrate transport. In this study, analytical deterministic model, CXTFIT, was used to simulate and to describe nitrate and chloride transport under different water table depths. The basis of the model is the solution to the convection-dispersion transport equation. This model allows estimation of transport parameters such as pore water velocity, dispersion coefficient and retardation factor and degradation rate as the main factors affecting in nitrate transport. Predicted and observed values of nitrate concentration were compared. Good agreement was

obtained between the observed and predicted values. The results suggest that nitrate degradation increases for the case of a fluctuating water table. Results of this simulation study indicate that the CXTFIT model can be employed to predict nitrate concentrations under water table management practices. More experimental and field observation data are required to improve the accuracy of the model predictions.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN AMALAN PENGUR USAN ARAS AIR BUMI KE ATAS PENGANGKUTAN BAHAN KIMIA PERTANIAN DALAM PERSEKITARAN BAWAH TANAH

Oleh

ABDUL HAKIM MASAUD MUSSA ALMDNY

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Memperce degradasi pencemar kimia pertanian secara mengawal aras air bumi memperkenalkan suatu ufuk baru dalam pengawalan pencemaran pertanian. Ujikaji dalam bidang ini menunjukkan degradasi bahan kimia pertanian seperti nitrat adalah bergantung kepada kandungan air tanah. Matlamat kajian ini adalah untuk menilai kesan turun-naik aras air bumi ke atas pengangkutan nitrat dan kloride . Satu set ujikaji menggunakan turus ujiun makmal telah dijalankan untuk menyiasat pengangkutan dua bahan non-sorptif iaitu nitrat dan, kloride (No_3, Cl) terhadap persekitaran bawah tanah terkesan oleh turun-naik aras air bumi. Tiga kedalaman aras airbumi dikwal pada 0.25 m, 0.50 m dan 0.75 m dari permukaan tanah, dan satu rawatan penyaliran bebas telah digunakan. Lengkung kepekatan nitrat yang berbeza telah diperolehi bagi pengukuran pada beberapa kedalaman. Perbezaan min dan puncak kepekatan nitrat menunjukkan perbezaan signifikan yang tinggi bagi kepekatan nitrat pada beberapa kedalamen. Dari nilai min dan puncak kepekatan

nitrat, kedalaman 25 cm dan 50cm memberikan min dan puncak yang terendah berbanding rawatan penyaliran bebas. Analisis statistik diskriptif menunjukkan ada perbezaan signifikan yang tinggi dalam min dan puncak kepekatan nitrat di antara berbagai rawatan aras air bumi. Keputusan ini mencadangkan keadaan tepu berkaitan dengan aras airbumi yang tinggi akan meningkatkan keupayaan degradasi nitrat. Lengkung kepekatan untuk klorida diukur pada kedalaman aras air bumi yang berbeza adalah sama, hanya berbeza sedikit pada nilai puncak dan min. Purata kadar perolehan semula klorida dalam semua rawatan aras air bumi ialah lebihkurang 91%. Keputusan ini menunjukkan bahawa klorida tidak terkesan oleh degradasi dan boleh digunakan sebagai unsure tracer konservatif bagi pengangkutan nitrat . Perbandingan di antara kepekatan nitrat dan klorida bagi berbagai kedalaman aras air bumi mengarah kepada kesimpulan bahawa aras air bumi adalah factor penting yang mempengaruhi pengankutan nitrat. Berdasarkan data ujikaji ini, nitrat mempunyai hubungan lelurus dengan klorida, dan boleh dinyatakan sebagai $NO_3 = k_c Cl$. Pekali lelurus k_c adalah terkesan oleh aras air bumi. Model satatistik (R^2= 0.83) untuk simulais pengurangan dan pengangkutan nitrat sebagaiman yang terkesan ol;eh aras air bumi yang berbeza ditentukan dan disesuaikan dengan data ujikaji. Keputusan simulasi menunjukan persetujuan yang memuaskan diantara ramalan dan data yang dicerap. Keputusan ini menunjukkan aras airbumi adalah factor penting dalam mempengaruhi pegangkutan bahan kimia. Keadaan anaerobic berpunca dari keadaan tepu telah meningkatkan potensi untuk degradasi bahan kimiayang lebih baik untuk mengurangkan pengangkutan nitrat. Dalam kajian ini model deterministic analitikal, CXTFIT, telah digunakan untuk simulasi dan untuk memperihalkan pengangkutan nitrat dan klorida degan pelbagai rawatan kedalaman aras air bumi. Model ini membenarkan anggaran parameter pengangkutan serpti halaju air liang, pekali sebaran, factor rencatan dan kadar degradasi sebagai factor terpenting dalam pengangkutan nitrat. Nilai kepekatan nitrat yang diramal dan tercerap telah dibandingkan . Pesetuijuan baik telah diperolehi di antara data tercerap dan nilai ramalan. Keputusan menunjukkan degradasi nitrat meningkat untuk kes aras air bumi yang turun-naik. Keputusan kajian simulasi ini menunjukkan model CXTFIT boleh digunakan untuk meramal kepekatan nitrat dalam pengurusan aras air bumi. Lebih banyak data kajian di lapangan adalah diperlukan untuk memperbaiki kejituan model ramalan tersebut.

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I certify that an Examination Committee met on 7th July 2003 to conduct the final examination of Abdul Hakim Masaud Mussa Al-Mdny on his Doctor of Philosophy thesis entitled " Effects of Water Table Management Practices on the Transport of Nitrates in Sandy Underground Environment" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded a relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.

ABDUL HAKIM MASAUD MUSSA

Date: 29 Sep 2003

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LIST OF ABBREVIATIONS

ME	Mean error
RMSE	Root mean square error
U	Theil's coefficient
R^2	Determination coefficient
r	Correlation coefficient
D	Dispersion coefficient
v	Pore water velocity
R	Retardation factor
μ	Degradation rate constant
S	Adsorbed concentration per unit mass of soled phase
CDE	Convection dispersion equation
CXTFIT	Program for analyzing contaminant transport in soil
ρ	Particle density of soil
D_b	Bulk density
$J_{\text{advection}}$	Mass flux of solute transported by advection
$J_{\text{dispersion}}$	Mass flux of solute transported by dispersion
SSQ (b)	Sum of squared residuals
Column A	Soil column with 0.25 m water table depth
Column B	Soil column with 0.50 m water table depth
Column C	Soil column with 0.75 m water table depth
Column D	Free drainage water table treatment (FD)
t	Time
d	Water table depth from the surface
S	Saturation depth
n	Volumetric water content
k	Distribution coefficient for the chemical
K	Hydraulic conductivity
p	Porosity
k_c	Coefficient of linear relation between nitrate and chloride
M_i	Measured result
Pi	Simulated result
SPSS	Statistical software
EEC	European Economic Community
WHO	World Health Organization
MEPA	Metrology and Environmental Protection Administration
USEPA	U S Environmental Protection Agency

CHAPTER 1

INTRODUCTION

General Introduction

Ground water is the main source of domestic, agricultural, and industrial supplies in many places of the world. It constitutes the largest available source of freshwater. Therefore, a proper development and utilization of this renewable natural resource are of interest for all water supply requirements. In any evaluation of groundwater resources, physical and biological characteristics of the water are of major importance in determining whether or not water is suitable for domestic, industrial, or agricultural use. With increasing demand for water and with the intensification of water utilization, the quality problem becomes the limiting factor in the development of water resources; especially in agricultural areas where exist variety of chemicals that can pass through the ground surface to the water table of the aquifer

The contaminations of groundwater by chemical substances from various point and non-point sources create many significant problems. Generally, groundwater contamination is traced back to environmental, agricultural, domestic and industrial sources. Environmental contamination can be due to the environment through which the flow of groundwater takes place. Seawater intrusion is an example of this pollution. Agricultural pollution can be due to irrigation and rainwater dissolving and carrying fertilizers and salts as they infiltrate through the ground surface and provide a major source of elevated nutrient levels to the subsurface water. Domestic and industrial contaminations can be caused by many ways such as percolation from septic tanks and artificial recharge of aquifers by sewage water. This study is concerned with groundwater pollution that is caused by agrochemicals.

Non point source pollution is a major problem associated with current intensive agricultural production methods. Surface and groundwater contamination from agricultural drainage water is of major environmental concern in the pursuit of sustainable agriculture. Groundwater in agricultural areas often has a distinct water quality signature composed of salt, nitrate, phosphorus, sediment, heavy metals, tracer elements, bacteria and pesticides. The sources of these compounds frequently come from agricultural chemicals such as fertilizers, pesticides and herbicides. These pollutants may destroy aquatic ecosystems and impair downstream water quality (Madramootoo, 1996).

Ground water monitoring programs throughout the world have revealed some pollution of groundwater supplies by nitrate and pesticides. Pollution of water resources by agricultural chemicals may cause health problem to humans. For example, a nitrate concentration in drinking water over 10 mg/l, the EPA safe drinking water limit, may cause clinical blue baby syndrome in infants. In additional to human health concerns, water pollution by agricultural chemicals affects fish and wildlife, commercial fisheries, recreational uses of surface waters, and water treatment facilities. Another concern is that once groundwater is contaminated, the problem is extremely difficult and expensive to remedy.

The potential for surface and groundwater pollution by agricultural chemicals lost from agricultural fields depends upon many factors including soil type, climate, geological, and agricultural management practices. To reduce subsurface water pollution from agricultural chemicals it is important to know the transport mechanisms and extent of their loss on a specific pathway. Researchers have investigated the mechanisms of chemical transport in soil profile under various conditions and identified several physical, chemicals and biological processes that control chemical behavior in soil. These processes are transport, sorption, transformation, degradation, volatilization, and plant uptake. The occurrence of each process depends upon pollutants characteristics, soil properties, microorganisms, environmental conditions, and the agricultural and water management practices employed. The interactions of these processes over time and space determine the fate of chemicals in soils. Subsurface flow is likely to be the major mechanism for the transport of soluble pollutants in many catchments areas, especially when water table approaches the soil surface. Pollutants such as nitrate, pesticides and herbicides which are normally applied in liquid or solid form, may be transported during runoff and join the river system to cause surface water pollution; they may also infiltrate into the soil and pollute the subsurface water. The increased infiltration of water, due to subsurface drainage may results in increased leaching and, subsequently, an increase in ground water contamination. Hallberg, (1986) has suggested that infiltration recharge may be the primary delivery mechanism of agricultural related contaminants to the ground water. The main factors affecting agricultural chemical loss from agricultural fields by leaching include the flow of water through the soil profile, and the amount of agrochemical for leaching at the time of water movement.

Many agrochemicals such as nitrate and pesticides are subjected to degradation in the environment. These agrochemicals are known to be degraded through both chemical and biological processes. Chemical reactions are mediated by soil properties, such as PH, or catalyzed by soil minerals. The usually moist and aerated upper layer of agricultural soils provides favorable conditions for chemical reactions, particularly hydrolysis and oxidation. In a natural environment it is often difficult to separate biological transformation from chemical transformation. The predominant means of transformation for wide variety of chemical compounds is biological, i.e., microbial or enzymatic. The kinetics of chemical compounds to degradation is effected by the quantity and availability of the chemicals, the presence of microorganisms or enzyme systems capable of degrading the chemicals, and the activity level of the microorganisms as affected by the nutrients available to sustain the microbial population and by environmental and soil conditions such as temperature, moisture, aeration, pH, organic matter and cation exchange capacity.

Researchers have examined various methods to reduce the effect of agricultural chemicals loads on the environment. Agricultural management practices such as chemical management and water table management are being considered to reduce the negative effects of the use of agrochemicals on groundwater. Water table management is defined as any system that influences the elevation of the shallow water table, including practices such as controlled surface drainage and subsurface drainage. Water table management has been used in poorly drained agricultural soils to control water table in the soil profile. Historically, subsurface drainage systems were not designed as water quality management tools, but they have an impact on chemical fate and transport within agricultural soils. Very little attention has been given to proper management of existing subsurface drainage systems and subsequent impact on ground water quality. These drainage systems actually provide the opportunity to detect some water quality problems, and then possibly control or eliminate the problems by controlling the water table to promote biological and chemical degradation of contaminants. Enhancing the degradation of agrochemicals by controlling the water table in the field has introduced a new horizon in agricultural pollution control. However, the use of water table management to enhance degradation of pollutants is a new area of research which hypothesized that the contamination of water bodies by agrochemicals transport from the agricultural areas through drainage systems can be substantially reduced or perhaps entirely prevented by water table management techniques.

Recently, water table management practices have received much attention as potential measures to reduce pollution hazard to groundwater. The greatest benefit of water table management practices on water quality has been its influence on the total nutrient loadings to drainage outflow (Evans et al., 1989). The reduction of agrochemical pollution such as nitrate and pesticides is attributed to enhanced denitrification as well as restricted outflow under water table management. Denitrification is a very complicated biological chemical process and the most important process for removing nitrate in water. It is an anaerobic process and is carried out by microorganisms, which use nitrate as their primary electron acceptor for obtaining energy from organic compounds. Because higher water tables reduce aeration and diffusion, denitrification is enhanced under water table management and excess nitrate is converted to its gaseous form to be returned to the atmosphere, rather than being leached to drainage water. Also, the shallow water table that persists for extended periods each year can create an anaerobic condition that could