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The effect of wetting and drying times on the fate of nitrogen species during soil aquifer treatment operation under Gaza city conditions

Master of Science Thesis
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تأثير فترات الترطيب والتجفيف على تغيرات مركبات النيتروجين في التربة خلال عمليات حقن الخزان الجوفي تحت ظروف مدينة غزة.

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DEDICATION

" To the souls of my father, my mother and my sister Maha, may God have mercy on them"

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ABSTRACT

Soil aquifer treatment (SAT) systems contribute to solving the problem of fresh water shortage in arid and semi arid regions. So, increasing interest is given to soil aquifer treatment (SAT) system to remove nitrogen species (ammonia, nitrate and nitrite) in treated wastewater by nitrification and denitrifiction processes to reduce groundwater pollution.

The purpose of this study is to simulate SAT system under Gaza city conditions by using 1 m height laboratory soil column which packed with 3 different natural soils respectively. The first soil was sandy loam soil (soil A) which consists of (73.8% sand, 14.4% clay and 11.8% silt), the second soil was sand soil (soil B) which consists of (93.3% sand, 4.6% clay and 2.1% silt) and the third soil was sand soil (soil C) which consists of (99.1% sand, 0.7% clay and 0.2% silt).

The soil columns were operated under two different operating schedules or wetting and drying cycles. The first wetting drying schedule was 24 hours wetting / 48 hours drying cycles and the second wetting drying schedule was 12 hours wetting / 12 hours drying cycles.

About 10 cm of synthetic wastewater head was ponded and controlled above the soil columns surface during wetting times. Soil solution samples were collected at three different depths of soil columns as a function of both space and time. The effect of wetting and drying times on the fate of nitrogen species in synthetic wastewater during SAT system operation under Gaza city conditions was investigated.

When the first and the second wetting drying schedules were applied on the soil C, the average of ammonia removal efficiency was 60.3% and 35% respectively and average of nitrate removal efficiency was 15% and 7% respectively.
When the first and the second wetting drying schedules were applied on the soil B at cold conditions the average of ammonia removal efficiency was 60.5% and 61% respectively, while the average of nitrate removal efficiency was insignificant.

Ammonia and nitrate removal were the highest, about 84% and 56% respectively when the first wetting drying schedules was applied on soil A.

The findings of this research confirm that the performance of SAT system to attenuate nitrogen species in wastewater was increased by applying the first wetting drying schedule (long wet and dry cycles) under elevated seasonal temperatures.

ملخص الدراسة

إن حقن الخزان الجوفي بالمياه العادمة المعالجة من خلال أحواض ترشيح يساهم في حل مشكلة نقص المياه في المناطق الجافة والشبه جافة. لذلك هناك اهتمام متزايد لدراسة امكانية إزالة مركبات النيتروجين (الأمونيا والنترات والنيتريت) من المياه العادمة أثناء تسربها داخل التربة بواسطة عمليات المعالجة الفيزيائية والكيميائية والبيولوجية.

الهدف من هذه الدراسة محاكاة نظام حقن الخزان الجوفي بالمياه العادمة في ظل ظروف مدينة غزة باستخدام طريقة عمود التربة, حيث انه تم استخدام ثلاث أنواع مختلفة من التربة في هذا العمود كلٌ على حدة وهي التربة (أ) وتتكون من (73,8% رمل و14,4% طين و 11,8% سلت) والتربة (ب) وتتكون من (93,3% رمل و 4,6% طين و2,1% سلت) والتربة (ج) وتتكون من (99,1% رمل و 0,7% طين و0,2% سلت) وتم تغذية عمود التربة بمياه عادمة مصنَّعة ذات تركيبة شبيهة بالمياه العادمة في مدينة غزة.

ومن اجل دراسة تأثير فترات الترطيب (ضخ المياه العادمة إلى سطح التربة) وفترات التجفيف على إزالة مركبات النيتروجين تم استخدام برنامجين مختلفين للترطيب والتجفيف, البرنامج الأول 24 ساعة ترطيب و48 ساعة تجفيف والبرنامج الثاني 12 ساعة ترطيب و12 ساعة تجفيف.

عند استخدام التربة (ج) في عمود التربة في شهري مارس و إبريل حيث درجات الحرارة أكثر ارتفاعا, أظهرت الدراسة أن معدل إزالة النترات كان 15% عند تنفيذ برنامج الترطيب والتجفيف الأول و حوالي 7% عند تنفيذ برنامج الترطيب والتجفيف الثاني أما معدل إزالة الأمونيا كان 60,3% عند تنفيذ برنامج الترطيب والتجفيف الأول و35% عند تنفيذ برنامج الترطيب والتجفيف الثاني.

وعند استخدام التربة (ب) في عمود التربة في شهري يناير وفبراير حيث كانت درجات الحرارة منخفضة, كان معدل إزالة النترات ضئيل جدا عند تنفيذ برنامج الترطيب والتجفيف الأول وحوالي 2% عند تنفيذ برنامج الترطيب والتجفيف الثاني أما معدل إزالة الأمونيا كان حوالي 60,5% عند تنفيذ برنامج الترطيب والتجفيف الأول و حوالي 61% عند تنفيذ برنامج الترطيب والتجفيف الثاني.

عند تنفيذ برنامج الترطيب والتجفيف الأول على التربة (أ) في شهر نوفمبر كان معدل إزالة الأمونيا والنترات الأكثر ارتفاعا حيث كان معدل إزالة الأمونيا 84% و معدل إزالة النترات 56%.

نتائج الدراسة تؤكد أن برنامج الترطيب والتجفيف الأول (فترات ترطيب وتجفيف أطول) له قدرة أعلى من برنامج الترطيب والتجفيف الثاني في إزالة مركبات النيتروجين من المياه العادمة عند حقنها عبر أحواض الترشيح ولكن في ظل درجات حرارة مرتفعة نسبيا.

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LIST OF SYMBOLS AND ABBREVIATIONS

NH_3	Ammonia
NH_4^+	Ammonium
NO_2^-	Nitrite
NO_3^-	Nitrate
N_2O	Nitrous oxide
ANAMMOX	Anaerobic Oxidation of Ammonia
APHA	American Public Health Association
AWWA	American Water Works Association
BOD	Biochemical Oxygen Demand
CAMP	Coastal Aquifer Management Program
CDG	German group (Carl Duisberg Gesellschaft)
CEC	Cation Exchange Capacity
CMWU	Coastal Municipality Water Utility
DNRA	Dissimilatory Reduction of Nitrate to Ammonium
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EPA	Environmental Protection Agency
EUNIDA	European Network of Implementing Development Agencies
GS	Gaza Strip
GWWTP	Gaza Wastewater Treatment Plant
HRT	Hydraulic Retention Time
KfW	German government-owned development bank
MCM	Million Cubic Meter
MOPIC	Ministry of Planning & International Cooperation
NCSWS	National Center for Sustainable Water Supply
NSU	Negotiations Support Unit
PCBS	Palestinian Central Bureau of Statistics
pH	Logarithmic measure of hydrogen ion concentration
PVC	Polyvinyl Chloride

PWA	Palestinian Water Authority
SAT	Soil Aquifer Treatment
SS	Suspended Solids
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Emergency Fund
UVA_{254}	Ultraviolet Light Absorbance at wavelength of 254 nm
WHO	World Health Organization
WWTPs	WasteWater Treatment Plants

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Nitrogen is one of the most common contaminants in groundwater, originating from agriculture and human and animal waste disposal (Heaton, 1986). Principle nitrogenous wastes that pollute the receiving water are ammonia (NH_3), nitrite ions (NO_2^-), and nitrate ions (NO_3^-). Significant pollution concerns related to the presence of nitrogenous wastes include dissolved oxygen (O_2) depletion, toxicity, eutrophication, and methemoglobinemia (Gerardi, 2002).

The wastewater-driven problems are usually characterized by high levels of nitrates in the groundwater, which are problematic in themselves, especially in relation to toxicity to infants and children (Almasri, 2008 and UNICEF, 2011). Ammonia (NH_3) is one of the most novice and common nitrogen compounds in wastewaters (Jorgenses, 2002 and Jellali et al., 2010).

one of the most important concerns in a SAT operation is to achieve nitrogen removal by allowing of nitrification of infiltrating ammonium and denitrification of its by-products, nitrate, to nitrogen gas. A properly designed and managed SAT system yields treated water that meets quality of our needs for unrestricted irrigation or other uses. (Abushbak 2004).

1.2 PROBLEM IDENTIFICATION

The Gaza Strip is classified as a semi-arid region and suffers from water scarcity. The renewable amount of water that replenishes the groundwater system is much less than the demanded amount, and this resulted in deterioration of the groundwater system in both quantitative and qualitative aspects (Nassar et al., 2010).

Water demand in the Gaza Strip is increasing continuously due to economic development and population increase resulting from natural growth and returnees, while the water resources are constant or even decreasing due to urban development (Hamdan, 2006). The increased demand for water has placed huge pressure on the

coastal aquifer system and with no other source of water available for Palestinians in Gaza have resorted to over-extraction from the Coastal Aquifer at a rate of 50-60 (MCM/year). This has caused the water table to drop below sea level and saline water to intrude rendering 90-95 percent unfit for human consumption (PWA, 2012).

In most parts of the Gaza Strip, especially around areas of intensive sewage infiltration, the nitrate level in groundwater is far above the WHO guideline of 45 mg/L. It is believed that the high concentrations of nitrate (more than 45 mg/L) in the area are caused by leaching of nitrate from wastewater to the aquifer (CAMP, 2000 and Shomar et al., 2004). An examination carried out by the United Nation Environment Program (UNEP) on a number of wells in the Gaza Strip found that the concentration of nitrates was six times higher than recommended level by the WHO (UNEP, 2009).

The Gaza Strip is facing a challenge by deficient and unbalance in the municipal water supply demand equation, since groundwater is still the main resource for water supply (PWA Data bank, 2003). Currently, the population of Gaza utilizes about 90 liter/capita/day of fresh water on average. This drives the over abstraction of the groundwater, but the volume used nevertheless remains well below the preferred minimum international guideline of 150 liter/capita/day. (WHO, 2004).

A national approach has been taken in the country to reuse the secondary treated wastewater produced from Gaza City Wastewater Treatment Plant to recharge the groundwater using soil aquifer treatment system (CDG et al., 2002).

1.3 AIM OF THE STUDY

The aim of the study is to investigate the effect of different wetting drying schedules on the fate of nitrogen species during SAT system operation by using different types of soils under Gaza city conditions.

1.4 THESIS STRUCTURE

This thesis consists of seven chapters as follows:

Chapter One (Introduction): Chapter one include general background about groundwater pollution with nitrogen compounds, problem identification and objectives of the study.

Chapter Two (Literature review): Chapter two covers a general literature review on SAT system including factors and parameters which affect SAT system performance and the types of nitrogen transformation.

Chapter Three (Description of the study area): chapter three describes the study area with respect to its location, population, topography, climate and existing waste water treatment facilities.

Chapter Four (Materials and methods): Chapter four discuses the methodology of study including the design of the experiment setup, soil column design, synthetic wastewater components and soil solution sampling and analysis.

Chapter Five (Results of the study): Chapter five presents the results and findings of this study including figures show the distribution of ammonia, nitrate, nitrite and UVA_{254} values of all experiments and tables represents the conditions of every experiment with respect to temperature drainage rate and date of the experiment.

Chapter six (General Discussion): The results and the findings of this study will be discussed and analyzed in chapter six.

Chapter Seven (Conclusions and Recommendations): Chapter seven presents the main conclusions and recommendations of study.

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL OVERVIEW ON SAT SYSTEM

Soil Aquifer Treatment (SAT) is defined as a three-component treatment process consisting of the infiltration zone, vadose zone and aquifer storage (Amy and Drewes, 2007). Infiltration and percolation through the soil improves reclaimed wastewater quality. Collectively, the water quality improvements that arise from percolation and groundwater transport and storage process are termed as soil aquifer treatment (Fox et al., 2005).

Soil aquifer treatment system is accomplished by infiltrating the wastewater from basin surface under operation schedule known as wetting drying schedule or cyclic pattern. The water percolates through the unsaturated soil to an underlying aquifer for storage and future use. As it flows through the soil additional treatment of the water occurs as result of physical, chemical, and biological processes (Bouwer & Rice, 1984; Idelovitch & Michail, 1984 and Wilson et al., 1995).

These reactions substantially reduce the levels of organic and inorganic compounds including nitrogen, phosphorus, suspended solids, pathogens and heavy metals leading to an improvement in water quality (Pescod, 1992 and Bdour et al., 2009). Mixing of the infiltrated wastewater with the groundwater and the slow movement through the aquifer increases the contact time with the aquifer material leading to further purification of the water (Asano and Cotruvo, 2004 and Dillon et al., 2006).

The hydraulic performance and the further purification of wastewater in the SAT system are both functions of the soil type (Quanrud et al., 1996), level of pretreatment (Levy et al., 1999), and the loading rates along with wet and dry scheduling of the basin (Kanarek et al., 1993).

SAT has been found to be a low cost sustainable tertiary wastewater treatment technology, which has the ability to generate high quality effluent from secondary

treated wastewater for potable and non-potable uses (Cha et al., 2006 and Fox et al., 2006). A schematic of soil aquifer treatment recharge basin is shown in figure (2.1).

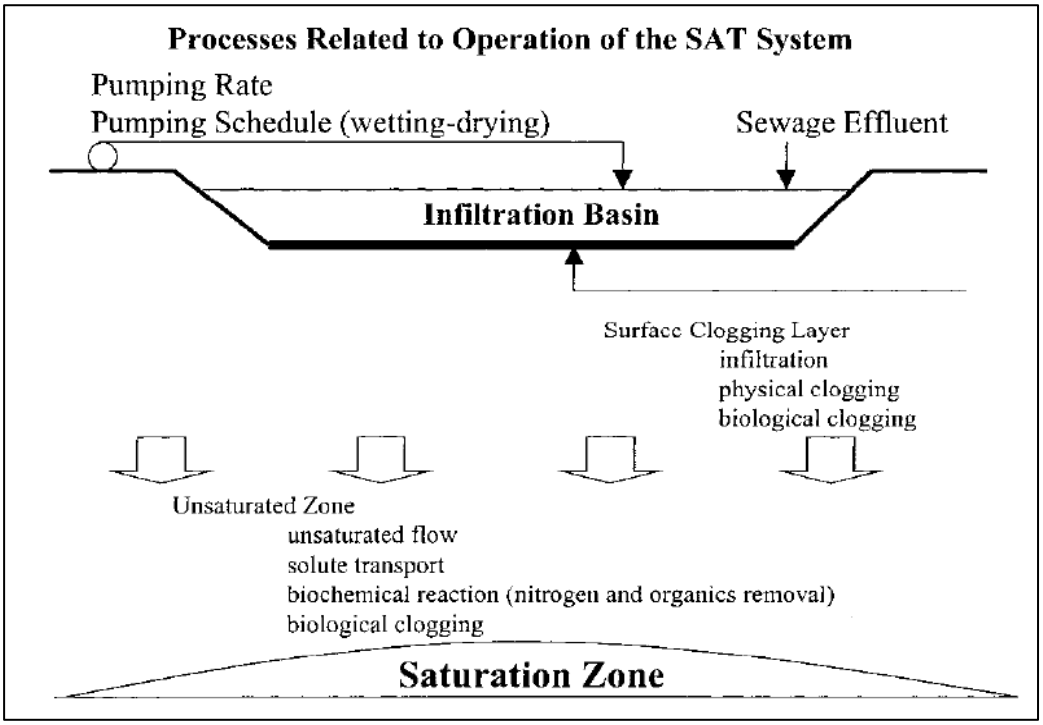

Figure 2.1: Schematic diagram of soil aquifer treatment recharge basin (Houston et al., 1999).

2.2 FACTOS AND PARAMETERS AFFECT SAT SYSTEM PERFORMANCE

2.2.1 QUALITY OF SAT SYSTEM WASTEWATER INFLUENT

The quality of wastewater prior to application to SAT system has an impact on SAT effluent quality. Near the soil water surface, biological activity with wastewater with high total oxygen demand will utilize all the dissolved oxygen leading to aerobic conditions in the saturated zone (NCSWS, 2001). Before the application of the municipal wastewater to the soil in the SAT system, it usually receives conventional primary and secondary treatment (Carlson et al., 1982), or even tertiary treatment (Wilson et al.,1995).

Higher nitrogen removal is likely to be achieved using primary effluents as compared to secondary effluents which is attributed to the availability of the carbon source for denitrification due to high organic concentration in primary effluents (Katukiza, 2006). But because of the to the potential risk of clogging in the surface due to the

suspended solids content present in the wastewater, the application of secondary effluent rather than primary effluent is more desirable in order to minimize clogging issues (Figueredo, 2007).

If the objective is to maximize the hydraulic acceptance of the system in order to minimize the land area required for spreading, a high degree of pretreatment (tertiary treatment) is justified. On the other hand, if the objective of the system is to use the unsaturated soil as a treatment system, then a lesser degree of pretreatment (secondary or primary treatment) may be justified (Abushbak, 2004).

2.2.2 WETTING AND DRYING TIMES

Wet-dry cycle operations consist of filling the pond to a certain depth, stopping the inflow (loading) and allowing the water to infiltrate into the ground. After all the water has infiltrated into the soil, the pond is left to dry for a period so that natural aeration can take place. During the drying period, water percolates and the infiltration potential for the next application period increases. (Li et al., 2000).

As shown in figure (2.2) the sum of total time of wetting (x) and total time of drying (y + z) which is drainage time and true drying time, is known as the cycle time or wetting drying schedule.

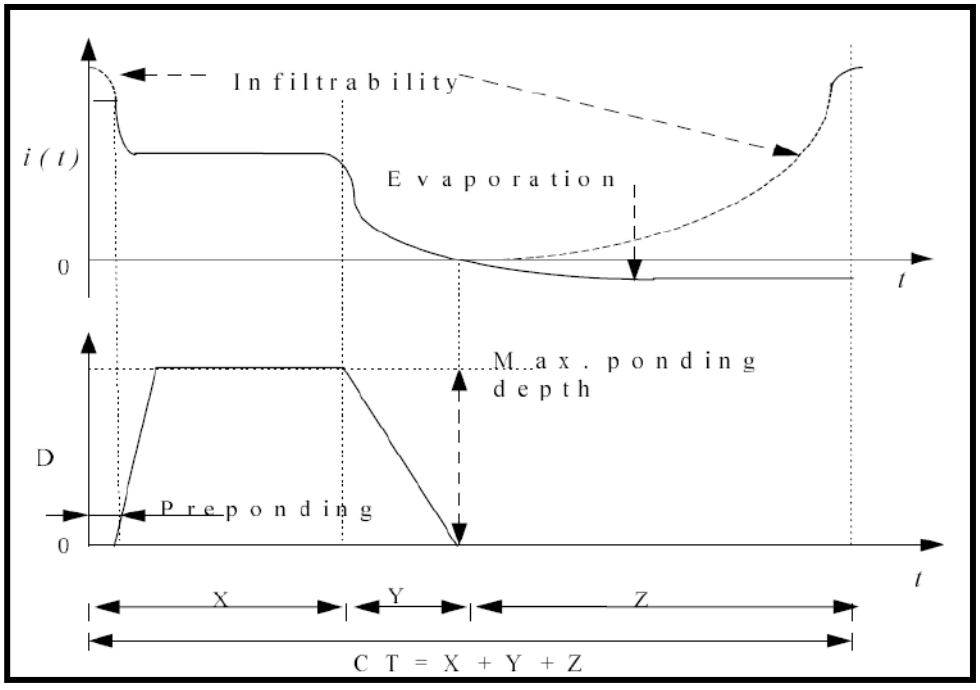

Figure 2.2: Wetting drying schedule (CT), infiltration rate *i* (t) and ponding depth(D). X: wetting time, Y: drainage time and Z: true drying time (Li et al,. 2000).

During soil aquifer treatment, cyclic wetting/drying of the basins is necessary for improvement of infiltration rates and to control aerobic/anaerobic conditions in the soil (Kopchynski et al., 1996). Aerobic condition during dry cycle allows oxygen to penetrate to greater depths as drying time is increased and allows for desiccation of the clogging layer and the recovery of infiltration rates during the next wetting cycle (Pescod, 1992). Increasing wet cycle times should increase the depth at which ammonia is adsorbed while increasing dry cycle time should increase the depth at which adsorbed ammonia is nitrified (NCSWS, 2001).

Wetting and drying cycles typically vary from 8-hours dry and 16 hours wetting to 2-weeks dry and 2-weeks wetting (Pescod, 1992). However, ammonia breakthrough due to high accumulation in the soil, can occur under continuous recharge conditions (Amy et al., 1993 and AWWA Research Foundation, 1998). SAT systems, therefore, should have a number of basins so that some basins can be wetted while others are drying (Pescod, 1992)..

2.2.3 SOIL OF INFILTRATION BASIN

Previous studies indicated that the performance of SAT systems is primarily controlled by soil type (Quanrud, 1996; AWWA Research Foundation,1998 and Houston, 1999). Soil properties can affect infiltration rate, bacterial attachment, re-aeration rates and adsorption (Fox et al., 2001a). The AWWA Research Foundation (1998) suggested that secondary wastewater effluents require soils with significant cation exchange capacity to adsorb ammonia. Additionally, after ten years of investigation at field scale projects,

The ideal porous medium for a SAT system operation is one that allows rapid infiltration and complete removal of all constituents of concern. Unfortunately, no such medium exists . However, the large pores in these soils are inefficient at filtering out contaminants, and the solid surface adjacent to the main flow paths are relatively noncreative. In contrast, fine-textured soils are efficient at contaminant adsorption and filtration, but they have low permeability and their small pores clog easily (AbuShbak, 2004).

Therefore, the best soils are in the texture range of sandy loam, loamy sand, and fine sand (EPA, 1973 and Bouwer, 1985). Such soils must have a sufficient depth before coarser material is encountered to minimize movement of suspended material into the soil and to avoid clogging of deeper soil layers (Goldenberg et al., 1993). However, Bouwer (1991) reported that all nitrogen biotransformation takes place in the upper 50 cm of the soil.

clay and other small soil particles could migrate downward due to the "seepage force" of the infiltrated water and accumulate a small distance (often only a few mm or less) below the surface where it can form a "micro" clogging or restricting layer. This process, called fine particle movement or wash-out wash-in, is an important factor in soil crusting due to rainfall and has been well documented in the soils literature (Sumner and Stewart, 1992).

2.2.4 POND DEPTH

The water depth in the infiltration basin should be kept relatively shallow because small depths promote fast turnover of the wastewater in the basins during wetting time and minimize growth of suspended algae that can form a filter cake on the surface (Bouwer and Rice, 1984), which causes precipitation of calcium carbonate due to pH increases as the algae remove carbon dioxide from the water during photosynthesis or other biological activities.

However, as the water depth is increased, the clogging layer is compressed and becomes less permeable (Bouwer et al., 1984). As a result of this, the increase in infiltration rate may only be moderate or even a decrease. In other words the infiltration rate does not increase in direct proportion to increasing the water depth in the basin.

2.2.5 HYDRAULIC PARAMETERS

The hydraulic parameters which have an effect on SAT systems include infiltration rate, permeability or porosity of the soil and hydraulic retention time.

2.2.5.1 INFILTRATION RATE

Performance of SAT is significantly depends on the infiltration rate. The slower the infiltration rate the higher will be clogging rate of the system. On the other hand higher infiltration rate declines the quality of the reclaimed water. Reduction in

infiltration rates leads to development of anaerobic conditions. This caused by physical clogging due to high suspended solids (SS) concentration and biological clogging during long wetting period even under low SS concentration. Infiltration rate has a direct impact on retention time and hence other dissolved organic carbon (DOC) removal (Drewes and Fox, 1999).

Infiltration rates in winter are often less than in summer due to cooler water with higher viscosity. Infiltration rates are site specific and are best evaluated on pilot basins or on actual systems. Schedule of flooding for optimum infiltration rates are developed by trial and error (Bouwer, 2002). Typical infiltration rates range from 0.5 to 3 m/day (2 to 12.5 cm per hour) during flooding (Bouwer, 2000).

2.2.5.2 PERMEABILITY

According to Bouwer (2002) SAT systems require permeable soils to get water into the ground and to the aquifer. Permeability depends on types of soil and porosity. During SAT clogging caused by biological processes and suspended solids at the infiltration interface reduces the permeability of soil leading to declined infiltration rates. Permeability affects percolation through the vadose zone and the treatment processes in SAT systems (Katukiza, 2006). Table 2.1 shows typical permeability values for different types of soil.

Table 2.1: Typical permeability values of the various soils (Bouwer, 2002).

Soil Type	Permeability (m/day)
Clay	<0.1
Loams	0.2
Sandy loams	0.3
Loamy sands	0.5
Fine sands	1.0
Medium sands	5.0
Course sands	>10.0

2.2.5.3 RETENTION TIME

SAT depends on hydraulic conditions in removing contaminants from water and therefore detention times have significant effect on the treatment processes. Microbial

activity in degradation of organic matter requires time for growth of microbial population under optimum conditions. Nitrification-denitrification process will not be complete under short retention time (Malolo, 2011). Infiltration rate has direct impact on retention time and hence DOC removal (Drewes and Fox, 1999).

2.2.6 CLOGGING

One of the main constraints of SAT systems is related to clogging problems. Thus, operation is enhanced by applying alternatively wet/dry cycles. This sequence limits the propensity for forming the schmutzdecke layer as results of spreading the reclaimed waters in the recharge basin (Figueredo, 2007 and Fernando, 2009). The clogging layer reduces the infiltration rate causing operation problems and therefore, the pond needs to be cleaned by draining, drying and scraping during dry cycles (Fernando, 2009 and Harun, 2007). Surface clogging phenomenon is also present even in freshwater recharge basins.

Two types of soil clogging layers have been classified during the operation of SAT systems: physical clogging and biological clogging.

2.2.6.1 PHYSICAL CLOGGING

In SAT system organic and inorganic suspended solids was found to be the dominant factor in creating the surface clogging. As the wastewater starts to penetrate the soil suspended solids that are larger in size than the soil pores does not penetrate and accumulate at the surface by means of straining (Bouwer, 1985 and Huisman & Olsthoorn, 1983) leading to the formation of a filter cake or clogging layer (Ger. schmutzdecke). This reduction of the suspended solids was found to take place on the surface and down to 100 mm depth (Vinten et al., 1983). The thickness of the clogging layer could reach to few millimeters in thick (Baveye et al., 1998) during SAT operation. The formed cake reduces the overall infiltrate rate of the basin.

2.2.6.2 BIOLOGICAL CLOGGING

It is also known as the biofilm or biomass. Biofilm is bacteria adsorbed to the soil surface. Sometimes (adsorbed) term is replaced by (attached) to express the bacteria linked to the soil. As it is attached to the solid phase it starts to grow and reproduce, at the interface of the water and soil phases, increasing the biomass and extracellular material. By which they link themselves together causing clogging. If clogging is

induced by the activity of microorganisms, one would expect that the addition of growth substrates should accelerate the process. For example, additions of carbon and energy sources such as plant residues accelerate and enhance biological soil clogging (Frankenberger et al., 1992).

2.2.7 TEMPERATURE

Physical factors that affect SAT processes include temperature, pH, oxygen concentration and electrical conductivity. Increase in temperature increases the microbial activity resulting in a fast biodegradation process (Sharma et al., 2007). Amatya et al,. (2009) reported that significant impacts of temperature on denitrification process were observed above 16^{o}C.

The optimum temperatures for bacterial activity are in the range from 25 to 35 °C. Aerobic digestion and nitrification stops when temperature rises to 50º C. When the temperature drops to about 15 °C methane-producing bacteria become quite inactive, and at about 5 ºC, the autotrophic-nitrifying practically cease functioning. At 2 °C even chemoheterotrophic bacteria acting on carbonaceous material become essentially dormant (Metcalf and Eddy, 2004).

The temperature dependence of the biological reaction-rate constants is very important in assessing the overall efficiency of a biological treatment process. Temperature not only influences the metabolic activities of microbial population but also has a profound effect on such factors as gas-transfer rates and settling characteristics of the biological solids (Metcalf and Eddy, 2004).The effect of temperature on the reaction rate of a biological process is expressed using the Vant's Hoff – Arrhenious relationship :

$$K_T = K_{20} \cdot \theta^{(T-20)} \qquad (2.1)$$

Where K_T = reaction rate coefficient at T, °C

K_{20} = reaction rate coefficient at 20 °C

θ = Temperature activity coefficient,

θ = 1.056 (20 – 30 °C) , θ = 1. 135 (4 – 20 °C)

T = Temperature, °C

Temperature dependence of denitrification can be represented by a modified Arrhenius equation:

$$DR_T = DR_{20} \cdot \theta^{(T-20)} \quad (2.2)$$

With DR_T and DR_{20} the denitrification rate (μmol N m^{-2} h^{-1}) at temperature T and 20 °C respectively, and θ a dimensionless temperature coefficient (Kadlec and Reddy, 2001).

2.3 NITROGEN TRANSFORMATION

Nitrogen species present in wastewater usually include various form of organic and inorganic nitrogen (ammonium, nitrite and nitrate). Transformation processes involved in the removal of nitrogen are dynamic and complex due to the different oxidation states of nitrogen and the ease of transformation from one state to the other (Crites et al., 2000).

2.3.1 TYPES OF NITROGEN TRANSFORMATION

Nitrogen exists in a number of chemical forms and undergoes chemical and biological reactions as shown in Figure 2.4. Denitrification, the microbial conversion of nitrate (NO_3^-) to nitrogen gas (N_2), is the main removal process of bio-available nitrogen in freshwater ecosystems (Seitzinger, 1988) it can remove more than half of the nitrogen inputs (de Klein, 2008). Apart from denitrification there are several other processes that can play an important role in nitrate removal and N_2-production, e.g. dissimilatory reduction of nitrate to ammonium (DNRA), anaerobic oxidation of ammonium (NH_4^+) with nitrite (NO_2^-) (anammox), and DNRA coupled to anammox (Burgin and Hamilton and 2007 and Kartal et al., 2007) .

DNRA is expected only to outcompete denitrification under low nitrate and oxygen conditions (Van de Leemput et al., 2011), and anammox only occurs at very low rates at the oxic-anoxic boundary (Thamdrup and Dalsgaard, 2002). Unlike denitrification DNRA does not remove bio-available N from the ecosystem. In addition to N_2, denitrification can result in the production of low concentrations of nitrous oxide (N_2O), an important greenhouse gas (Seitzinger et al., 2006 and Burgin and Hamilton, 2007).

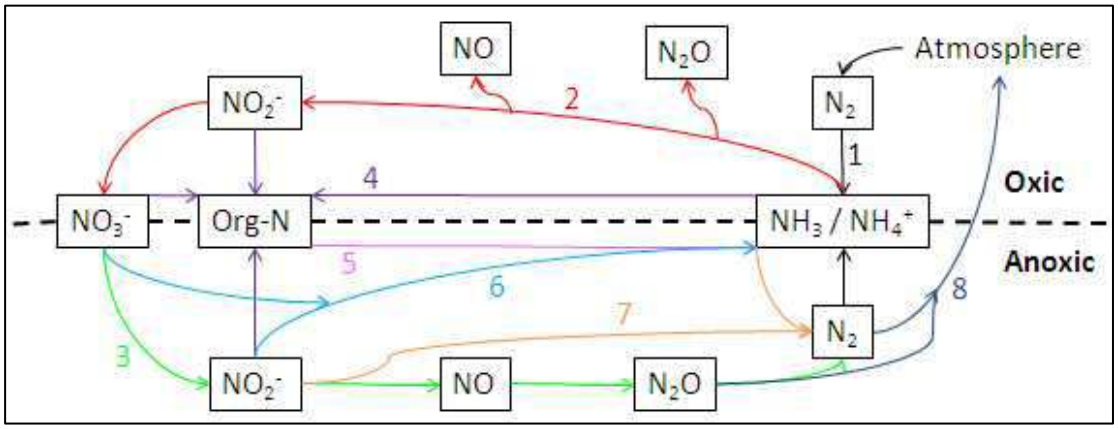

Figure 2.4: Schematic overview of N-pathways. 1: N-fixation, 2: nitrification, 3: denitrification, 4: assimilation, 5: mineralisation, 6: DNRA, 7: anammox, 8: volatilisation

2.3.1.1 NITRIFICATION

The biological conversion of ammonia/ammonium to nitrate is called Nitrification. Nitrification is a two-step process. Bacteria known as Nitrosomonas convert ammonia and ammonium to nitrite. Next, bacteria called Nitrobacter finish the conversion of nitrite to nitrate. These bacteria, known as "nitrifiers," are strict "aerobes;" meaning, they must have free dissolved oxygen to perform their work. Nitrification occurs only under aerobic conditions at dissolved oxygen levels of 1.0 mg/L or more. The optimum pH for Nitrosomonas and Nitrobacter is between 7.5 and 8.5. The nitrification reaction consumes 7.1 mg/L of alkalinity (as $CaCO_3$) for each mg/L of ammonia nitrogen oxidized.

During nitrification, bacteria assimilate NH_4^+ into cell mass. The energy needed for cell synthesis for nitrifiers is derived chemically from the oxidation of NH_4^+, and derive cell carbon from inorganic carbon. The overall biological nitrification process is described by the chemical reaction as:

$$NH_4^+ + 1.83O_2 + 1.98HCO_3^- \rightarrow 0.021C_5H_7O_2N + 0.98NO_3^- + 1.04H_2O + 1.88H_2CO_3 \quad \textbf{(2.3)}$$

The formed nitrite NO_2^- in soil environment is so quickly oxidized to nitrate NO_3^- that it rarely accumulates:

$$NO_2^- + 1/2\ O_2 \rightarrow NO_3^- \quad \textbf{(2.4)}$$

In most soils NO_3^- is not adsorbed, and it moves readily in the soil solution. If large quantities of wastewater is applied to the land, NO_3^- will move downward and may

eventually reach the groundwater. However, whether NO_3^- is formed from input NH_4^+ or is initially present in the wastewater, it is subject to denitrification under the denitrification conditions of the soil which may prevent at least some of it from moving downward (Abushbak 2004).

2.3.1.3 DENITRIFICATION

The biological reduction of nitrate (NO_3^-) to nitrogen gas (N_2) by facultative heterotrophic bacteria is called denitrification. Tan C et. al, (2013) reported that nitrate could be removed by denitrification at low dissolved oxygen levels, but the removal rate was gradually reduced as the dissolved oxygen concentration increased to a higher level of 6.0 mg/L.

NO_3^- is assimilated into cell mass during biological denitrification mechanism as:

$$NO_3^- + 1.08CH_3OH + H^+ \rightarrow 0.065C_5H_7O_2N + 2.44H_2O + 0.76CO_2 + 0.47N_2 \quad \textbf{(2.5)}$$

Where the methanol CH_3OH is considered as the carbon source for both energy and synthesis reactions (other forms of organic carbon may present in the wastewater and may be used as a carbon source for the denitrification process). The rate of this process depends on the concentration of NO_3^- and is influenced by the concentration of organic carbon as an electron acceptor as well as the concentration of oxygen in the system (Abushbak 2004).

Temperature affects the growth rate of denitrifying organisms, with greater growth rate at higher temperatures. Denitrification can occur between 5 and 30 °C, and these rates increase with temperature and type of organic source present. The highest growth rate can be found when using methanol or acetic acid. A slightly lower rate using raw wastewater will occur, and the lowest growth rates are found when relying on endogenous carbon sources at low water temperatures. Onnis-Hayden and Gu, (2008) have mentioned in their study that the lower denitrification rates associated with glucose are most probably associated to the more complex degradation pathway thought which bacteria derive energy from sugars.

2.3.1.5 ANAEROBIC AMMONIUM OXIDATION

Under conditions of limiting available carbon and in the absence of oxygen, it is thermodynamically possible that several other alternate electron acceptors can potentially oxidize NH_4^+ to N_2. However, this pathway assumes that some anaerobic

bacteria are capable of using NH_4^+ as an electron donor and derive energy through oxidation.

Ammonium oxidation to N_2 using nitrate (NO_3^-) or nitrite (NO_2^-) as an electron acceptor is commonly now known as the "anammox" process (Mulder et al., 1995). The proposed reactions for this process are shown below:

$$5NH_4^+ + 3NO_3^- = 4N_2 + 9H_2O + 2H^+ \quad \textbf{(2.6)}$$

$$NH_4^+ + NO_2^- = N_2 + 2H_2O \quad \textbf{(2.7)}$$

2.3.1.6 AMMONIUM VOLATILIZATION

Ammonium would be largely transformed into ammonia if water or soil pH are between 8 and 9 and the potential of ammonia volatilization would be increased (Rao et al. 1984).

As soil pH increases, the fraction of soil-solution NH_4^+ plus soil-solution NH_3 in the NH_3 form also increases by an order of magnitude for every unit of pH above 6.0, thus increasing losses of soil-solution NH_3 to the atmosphere.

$$NH_4^+ + OH^- \rightarrow NH_3\,(gas) + H_2O \quad \textbf{(2.8)}$$

Stevenson (1986), summarized NH_3 volatilization:

1- Is of most importance on calcareous soils, especially as soil pH exceeds 7.
2- losses increase with temperature and can be appreciable for neutral or alkaline soils as they dry out.
3- Is greater in soils of low CEC, such as sand.

2.3.1.7 NITRATE LEACHING

Leaching is one of the two important mechanisms of nitrate losses (leaching and denitrification). NO_3^- in solution is highly mobile in the soil until it is immobilized (assimilated) by micro-organisms or assimilated by plants. Nitrate (NO_3^-) is a negatively charged ion that is repelled by (rather than attracted to) negatively charged clay mineral surfaces in soil (the CEC). It is the primary form of N leached into groundwater, is totally soluble at the concentrations found in soil, and moves freely through most soils. As described by Jury and Nielson (1989), movement of the NO_3^- ion through soil is governed by convection, or mass-flow, with the moving soil solution and by diffusion within the soil solution. The widespread appearance of NO_3^-

in groundwater is a consequence of its high solubility, mobility, and easy displacement by water.

Infiltration rate, that is related to soil slope, land use, stability of soil aggregates, the moisture content and all factors affecting size and continuity of soil pores. Interactions with soil constituents: Sandy, light textured soils generally have a fairly uniform porosity. They retain less water than clayey, heavily textured soils and nitrates can be leached with relatively small amount of rainfall. By contrast, finer textured homogeneous clayey soils favour chemical processes (exchange of anions and cations) and retain more nitrate and water.

CHAPTER THREE

DISCRIPTION OF THE STUDY AREA

3.1 INTRODUCTION

The Palestinian territories consist of the West Bank with approximately 5,800 km^2 and the Gaza Strip with about 378 km^2 (Figure 3.1).

The West Bank area is made up of a hilly region in the West and the Jordan Valley in the East. The climate in the West Bank can be characterized as hot and dry during summer and cool and wet in winter. The Gaza Strip has a Mediterranean climate and consists mainly of coastal dune sands, being located between the coast and the Negev and Sinai Deserts. (MOPIC, 1998)

3.2 GAZA STRIP

The Gaza Strip (GS) area is a part of the Palestinian territories. It is located at the eastern coast of the Mediterranean Sea between longitudes 34° 2" and 34° 25" east, and latitudes 31° 16" and 31° 45" north (Aish, 2010 and UNEP, 2003).

The Gaza Strip is considered one of the denser places in the world. The total population of Gaza Strip at mid 2011 was about 1.59 million inhabitants with population density particularly in the Gaza Strip is 4353 persons/km^2 (PCBS, 2011).

The Gaza Strip is considered as a semi-arid climate conditions. Annual precipitation is approximately 446 mm/year according to Palestinian meteorological data. The raining season is from October to April.

Scarcity of water is strongly present in the Gaza Strip, the only source of water is the groundwater, which is considered as a major problem and always voluntary for pollution, because the soil profile is consist of sand, sand stone and gravel mainly (El-Nakhala, 2012).

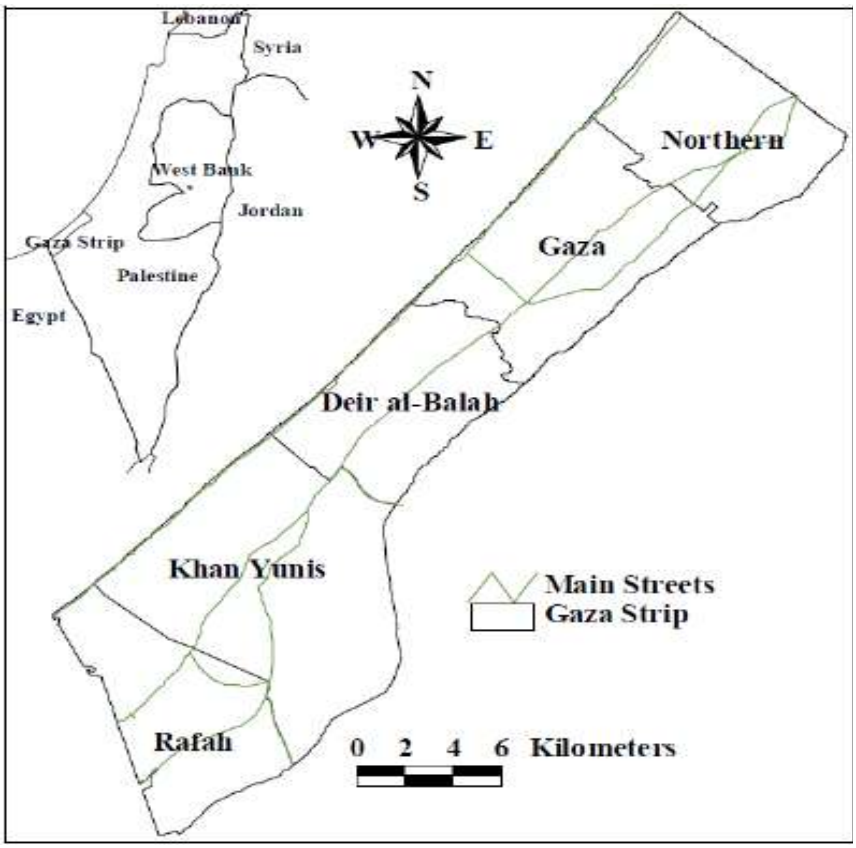

Figure 3.1: Map of the Gaza Strip (Aish, 2010).

3.2.1 METEOROLOGY OF THE GAZA STRIP

There are two well-defined seasons, the wet season, starting in October and extending into April, and the dry season from May to September. The average daily mean temperature ranges from 25°C in summer to 13°C in winter, with the average daily maximum temperature ranging from 29°C to 17°C, and the minimum temperature ranging from 21°C to 9°C, in the summer and winter, respectively. The daily relative humidity fluctuates from 65% in the day time to 85% at night in the summer and between 60% and 80%, respectively, in the winter. The mean annual solar radiation is 2200 J/cm^2/day. There is a significant variation in the wind speed during the day time, and the average maximum wind speed velocity is about 3.9 m/s.

(CAMP, 2000).

3.2.2 EXISTING WASTEWATER TREATMENT PLANTS IN THE GAZA STIP

There are three wastewater treatment plants (WWTPs) in the Gaza Strip (Figure 3.2), Beit Lahia Plant which serves North Gaza Governorate with an average daily flow rate of 18,000 m^3, Gaza Plant which serves Gaza City and the Beach Camp with an

average daily flow rate of about 50,000 m^3 and Rafah waste water Plant which serves Rafah Governorate with an average daily flow rate of 12,000 m^3.

The three WWTPs are overloaded and have limited treatment efficiency, ranging from 30 - 60%. About 7,000 m^3 of raw wastewater from the Middle Gaza Governorate is discharged directly to Wadi Gaza mixing with storm water, which then flows directly to the sea (EUNIDA, 2009).

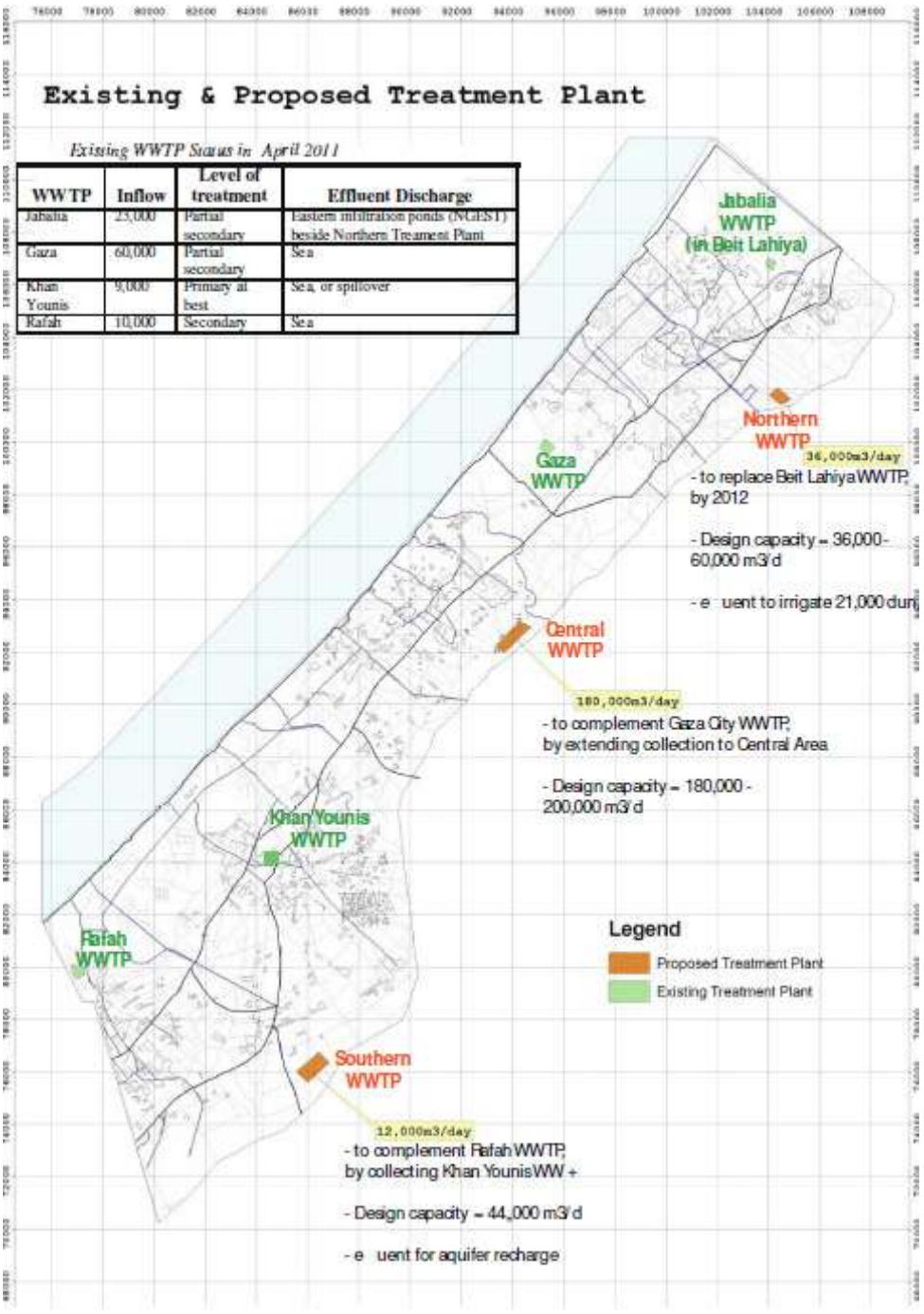

Figure 3.2: Existing and proposed wastewater treatment plants in the Gaza Strip (PWA, 2011).

3.2.3 GAZA CITY WASTEWATER TREATMENT PLANT

The Gaza Wastewater Treatment Plant (GWWTP) (Figure 3.3) serves the municipality of Gaza and part of the North Gaza Governorate, although the latter area is expected eventually to be diverted to the Northern WWTP. The GWWTP plant is located on an elevated position to the south of the city (in Sheikh Ejleen area). The plant covers an area of 130,000 m^2.

Originally, the plant was constructed in 1977 as a two-pond treatment system. It was expanded in 1986 by UNDP when two additional ponds were constructed. Part of this expansion included reuse facilities, consisting of three large recharge basins, a booster pumping stations, a 5.000 m^3 storage tank, a distribution piping system and an overflow pipeline to the Wadi Gaza. Modifications were made in 1996 including the addition of two "bio-tower" trickling filters.

In 2006, the Gaza Municipality commenced construction of an additional fourth anaerobic pond. Currently, CMWU and the Municipality of Gaza are upgrading the plant for improving the effluent quality on the medium term (PWA, 2011).

Figure 3.3: Aerial Photo of the Gaza City Wastewater Treatment Plant (CMWU, 2012).

3.2.3.1 WASTEWATER EFFLUENT CHARACTERIZATION

The secondary effluent from GWWTP was characterized by measuring relevant physical and chemical water quality parameters directly after its collection as grab sample. The results are presented in table (3.1). The chloride concentration was found 900 mg/l which is considered high level for agricultural reuse. The oxidized form of nitrogen (nitrate) concentration is found 19 mg/l which is accepted for reuse while the ammonia concentration is considered to be very high. The Palestinian Standards of wastewater effluent recharge are set at 600 mg/l for chloride and 20 mg/l for nitrate (KfW, 2005).

Table 3.1: Characterization of wastewater from GWWTP (Al Khateb, 2012)

No.	Parameter	Unit	Result
1	pH	-	7.3
2	E.C	µS/cm	4300
3	TDS	mg/l	2666
4	Nitrite	mg/l as NO_2^-	1.8
5	Nitrate	mg/l as NO_3^-	19
6	Ammonia	mg/l as NH_3	71.8
7	Chloride	mg/l as CL^-	900
8	Sulphate	mg/l as SO_4^{-2}	81.3
9	Alkalinity	mg/l as $CaCO_3$	1057
10	Hardness	mg/l as $CaCO_3$	708
11	Calcium	mg/l as Ca^{+2}	140
12	Magnesium	mg/l as Mg^{+2}	87
13	Potassium	mg/l as K^+	34.9
14	Sodium	mg/l as Na^+	580
15	COD	mg/l as O_2	245
16	BOD_5	mg/l as O_2	125

3.2.3.2 GAZA CITY REUSE FACILITIES

The expansion during 1987, as part of a reuse system under United Nations Development Program (UNDP) funding, included constructions of reuse facilities consisting of three large recharge basins, a booster pumping stations, a 5,000 m^3 storage tank, a distribution piping system and overflow pipeline terminating at the Wadi Gaza. The three infiltration basins are 38,290 m^2 in area. They are located approximately 850 m southeast of the Gaza Wastewater Treatment Plant.

The basins were not used until April 1998 due to the unacceptable quality of the plant's effluent. Since 1998, the Gaza Wastewater Treatment Plant has typical disposed approximately 20,000 m^3/day effluent via these basins, with the remaining effluent being discharged to the Wadi Gaza or the Mediterranean Sea. Under a separate demonstration project, the three existing infiltration basins, associated with the Gaza Wastewater Treatment Plant, will be expanded to five basins.

The total area of infiltration basins will become 176,000 m^2. And that a minimum of 20,000 m^3/day to a maximum of 75,000 m^3 /day of treated wastewater can be infiltrated into the aquifer. This infiltrated effluent will be later extracted via recovery wells to irrigate nearby farms. (Abushbak 2004).

The operation of the three existing infiltration basins (Figure 3.4) , as described by Metcalf and Eddy (Metcalf & Eddy, 1997), is premised on an application rate of 8,900 m^3/day at pond one, 11,570 m^3/day at pond two and 5,460 m^3/day at pond three. Each pond will permit a maximum head buildup of 0.5 m. With the availability of three ponds the operation of the ponds is suggested to be carried out by a 1 day wetting/ 2 days drying cycle. However, the SAT system in the Gaza Strip does not work at its full capacity (CDG et al., 2002).

Figure 3.4: Inlet of the infiltration basin at the Gaza City wastewater Treatment Plant

CHAPTER FOUR

MATERIALS AND METHODS

4.1 INTRODUCTION

Soil column experiments were carried out at laboratory scale to simulate SAT system with respect to nitrogen species (ammonia, nitrate and nitrite) removal. During the research period, data were collected from the chemical analysis which carried on the soil solution to evaluate the removal trends of nitrogen species. The materials, experiment setup and experiments procedures that were used during this research are delineated below.

4.2 DESIGN OF THE EXPERIMENT SETUP

The experiment setup for this study consisted as shown in figure 4.1 of one 500 liter ground storage tank which were used for preparation of the synthetic wastewater, soil column and 250 liter storage tank (elevated/overhead tank). The prepared synthetic wastewater was pumped from the 500 liter storage tank by an electrical pump to the 250 liter storage tank which placed higher than the soil column. During wetting time, the synthetic wastewater flowed down from the elevated tank by gravity through water ball valve and was and then applied at the top of the soil column surface.

Figures 4.1: The experiment setup.

4.3 SOIL COLUMN DESIGN

To achieve the objectives of this study, a soil column experiments were deployed to simulate Gaza City SAT system. Therefore a polyvinyl chloride pipe (PVC) which had 20 cm internal diameter and 100 cm length was used for the soil column as shown in figure 4.2. At the bottom of column a metal mesh screen was plugged and a funnel was mounted at the end of the column for the drainage of wastewater.

About 10 cm height of small stones were filled above the screen to prevent soil escape with the percolated wastewater. The selected soils were passed through 2 mm mesh sieve and packed dry into the column, soil height above the small stones was 60 cm. A mechanical float valve was installed at the top of the PVC column (Figure 4.3) to control a level of 10 cm synthetic wastewater pond above the soil surface.

Figure 4.2: The used soil column.

Figure 4.3: Mechanical float valve.

4.4 SYNTHETIC WASTEWATER COMPONENTS

The properties of natural wastewater change rapidly with time due to many different factors, for this reason synthetic wastewater was used in the experiments. The ratio of carbon to nitrogen of synthetic wastewater was adjusted to be about (2 : 1) which is approximately similar to the ratio in the natural wastewater effluent in Gaza City Wastewater Treatment Plant. The composition of synthetic wastewater was as follows:

a) 38.214 mg L^{-1} (10 mg L^{-1} as N) ammonium chloride (NH_4Cl) as source of ammonia.
b) 37.5 mg L^{-1} (15 mg L^{-1} as C) glucose ($C_6H_{12}O_6$) as source of organic carbon.
c) 104.9 mg L^{-1} (15 mg L^{-1} as C) sodium bicarbonate ($NaHCO_3$) as source of inorganic carbon.
d) 36-58 mg L^{-1} (5-8 mg L^{-1} as N) potassium nitrate (KNO_3) as source of nitrates.

To prepare 500 liters of synthetic wastewater, these quantities were multiplied by 500 and dissolved in one liter of filtered water and then was added to a tank containing 500 liters of filtered water and mixed very well. Concentration of nitrate in the filtered water was detected before preparing the synthetic wastewater and has been taken into account.

4.5 SOIL SOLUTION SAMPLEING AND ANALYSIS

The techniques, reagents and apparatus used to measure different parameters during the study are delineated below.

4.5.1 SAMPLES COLLECTION

Soil solution samples were collected as shown in Figure 4.4 from two intermediate sampling ports at a distance of 20 cm and 40 cm from the soil surface by using soil solution sampling units (Rhizon soil moisture samplers), and from the drainage of the wastewater at the bottom of soil column, which represented sampling at 60 cm depth of the soil.

Figure 4.4: Sampling points

Concentration of ammonia and nitrate were tested at the samples which were collected from the inlet of the synthetic wastewater, the two intermediate sampling ports of the soil column and from the drainage of the wastewater.
While the concentration of nitrite and the UVA_{254} values were tested at the samples which were collected from the inlet and from the drainage of the wastewater.

Soil solution samples were collected during the wetting times from the three different soil depths (20, 40 and 60 cm) at the same time approximately, and as a function of both space and time.

4.5.2 SAMPLES TRANSPORTATION AND STORAGE

The collected soil solution samples were stored in a refrigerator at 4°C to retard any biochemical and chemical reactions or changes may happened during samples transportation and storage. Samples tests were carried in the water science laboratory at Al-Azhar university.

4.5.3 SAMPLES ANALYSIS

Collected samples were analyzed to measure the target soil solution parameters (Ammonia, Nitrate, Nitrite and UVA_{254}).
The analytical methods to determine these parameters were done according to the standard methods for the examination of water and wastewater (APHA, 2005) as follows:

- Ammonia (NH_3) was measured using Phenate Spectrophotometric method which consisted of the preparation of reagents and standards. The standards were made by diluting the stock solution to 50 ml. The calibration curve of ammonia concentration Vs absorbance was prepared using the stock solution of Ammonium chloride and a series of standards solution. Ammonia was determined using the standard curve after measuring the absorbance at 640 nm of standards and samples using UV-1601 Shimadzu spectrophotometer (Figures 4.6 & 4.7).

Figure 4.6: Determining of ammonia in soil solution samples.

Figure 4.7: UV-1601 Shimadzu spectrophotometer.

- Nitrate was measured by using UV Spectrophotometric method. Nitrate was determined by using the standard curve after measuring the absorbance at 220 nm of standard solutions and soil solution samples using UV-1601 Shimadzu spectrophotometer. The calibration curve of nitrate concentration versus absorbance was prepared using the stock solution of Potassium Nitrate.
- Nitrite was analyzed by using UV-1601 Shimadzu spectrophotometer. The method is based on the reaction of nitrite ions with sulfanylamide in acidic medium and the diazo compound obtained further reacts with diamine yielding an azo color. The nitrite ion concentration is determined by measuring the absorbance of the azo color at 525 nm. the red colored dye formed was measured at the specified absorbance against a series of standard solutions to prepare the calibration curve. The concentrations of the samples were determined by using the calibration curve.
- Ultraviolet light absorbance at wavelength of 254 nm (UVA_{254}) was measured as an indicator for organic mater removal. Shimadzu UV-1601 spectrophotometer was used to measure the UV absorbance at wavelength of 254 nm. Zero absorbance standard as blank was established with ultra-pure water to auto-zero the spectrophotometer. The samples, first filtered through a 0.45 μm filter were analyzed. Before measuring, the cuvette was properly cleaned and dried with tissue paper and rinsed once more with the sample. The

orientation of the cuvette was kept the same for all samples to the auto-zeroed sample.

4.6 SOIL COLUMN OPERATION

The soil column has been operated under two different operating schedules or cyclic patterns during this study to evaluate the effect of wetting and drying times on the removal of nitrogen species . The two operating schedule are presented in table 4.1:

Table 4.1: Operating schedules of the experiments.

Operation schedule description	Wetting time	Drying time
1- First wetting drying schedule	24 hours	48 hours
2- Second wetting drying schedule	12 hours	12 hours

4.7 SOILS SELECTION

Three different types of soil has been used during this study, which are namely soil A, soil B and soil C. Soil C was colleted from the actual infiltration basin which exists in Sheikh Ejleen wastewater treatment plant in Gaza city, while soils A and B were collected from two different areas close to the Sheikh Ejleen wastewater treatment plant. Physical and chemical characteristics of the three types of soil were tested.

The soil column was packed and operated by using the three soil types sequentially. At first, the soil column was filled and operated by using soil A, and then at the end of experiments by using soil A, the column was cleaned with distilled water and then it was packed and operated by using soil B. At the end of experiments by using soil B, the same procedures was used to clean the column which packed and operated by using soil C.

CHAPTER FIVE

RESULTS OF THE STUDY

5.1 INTRODUCTION:

Attenuation of nitrogen concentration during different SAT process conditions was assessed using laboratory soil column experiments. Characterization of the synthetic wastewater is imperative to assess changes in wastewater quality with regard to nitrogen species (Ammonia, Nitrate and Nitrite). The experiments of this research as mentioned before were carried out by applying two different wetting drying schedules and by using three types of soil. Physical and chemical characteristics of the three used soils (soil A, soil B and soil C) are presented in table 5.1:

Table 5.1: Physical and chemical characteristics of the soils A, B and C .

No.	Parameter	Unit	Soil A	Soil B	Soil C
1	Sand %	-	73.8	93.3	99.1
2	Clay %	-	14.4	4.6	0.7
3	Silt %	-	11.8	2.1	0.2
4	Packed soil density	$g\ cm^{-3}$	1.258	1.433	1.48
5	Particle density	$g\ cm^{-3}$	2.622	2.66	2.613
6	Porosity	-	52	46.1	43.1
7	Weight of the soil	Kg	23.7	27	27.9
8	PH	-	7.98	8.19	8.56
9	CEC	$meq\ (100\ g)^{-1}$	3.8	2.8	2.1
10	EC	$micromho\ cm^{-1}$	158	210	160
11	TDS	$mg\ L^{-1}$	98	130.2	99.2

The experiments of this study were distributed into five sets of experiments according to the type of the used soil and the applied wetting drying schedules as presented in table 5.2:

Table 5.2: Sets of the experiments

Description of the set	Soil type	Operating schedule	No. of cycles
First set of experiments	Soil A	First wetting drying schedule	1
Second set of experiments	Soil B	First wetting drying schedule	9
Third set of experiments	Soil B	Second wetting drying schedule	6
Fourth set of experiments	Soil C	First wetting drying schedule	8
Fifth set of experiments	Soil C	Second wetting drying schedule	6

5.3 EXPERIMENT BY USING SOIL A

Soil (A) was used in the first experiments in order to study the distribution of nitrogen species through SAT column and the removal efficiency of the system.

5.3.1 RESULTS OF THE FIRST SET OF EXPERIMENTS: EXPERIMENT (No. 1) USING SOIL (A) – FIRST WETTING DRYING SCHEDULE

5.3.1.1 Experiment No. 1:

The first experiment was operated by applying the first wetting drying schedule **(24 hours wetting time and 48 hours drying time).** Table 5.3 concludes the conditions of experiment No. 1 with respect to date of experiment, temperature degrees and drainage rate.

Table 5.3: Conditions of experiment No. 1:

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 11 Nov. 2012 (afternoon)	Max. 26 Min. 18
Until: 12 Nov. 2012 (afternoon)	Max. 25 Min. 17
Drainage Rate	**ml/min**
At the beginning of the wetting time	60
At the middle of the wetting time	40
At the end of the wetting time	20

5.3.1.2 Ammonia removal:

High percentage of initial ammonia removal was observed at the different depths of the soil column during the wetting time of this experiment, especially at the first seven hours of the wetting time as shown in figure 5.1, due to the stored oxygen in the soil in addition to the dissolved oxygen in the synthetic wastewater which increased the performance of nitrification process.

The high percentage of clay and silt in soil A increased also its cation exchange capacity (CEC) which increased the rate of ammonia adsorption to the soil particles and the nitrification performance. The average of hydraulic retention time (HRT) was about 9 hours which enhanced also the adsorption and the nitrification rate of ammonia.

the efficiency of initial ammonia reduction in this experiment was 84% after 24 hours of wetting time at the outlet of the soil column (60 cm depth of the soil), while it was 62% and 45% at 40 cm and 20 cm depths of the soil respectively.

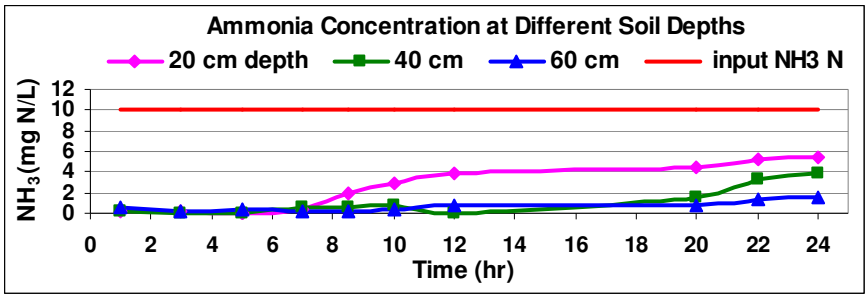

Figure 5.1: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (A) – (Cycle One - First Run - First Wetting Drying schedule).

5.3.1.3 Nitrate removal:

High removal of initial nitrates was observed also during the wetting time of this experiment as shown in figure 5.2 which shows the distribution of nitrate concentration at different soil depths.

The nitrate removal efficiency increased significantly at 60 cm depth of the soil after ten hours of wetting time, because the dissolved oxygen was consumed more and more with an increase of wetting time which resulted in an increase of the denitrification performance. Peaks of nitrate concentration were observed approximately after seven and nine hours of wetting time because of simultaneous nitrification and denitrification.

The efficiency of initial nitrates removal at the outlet of the soil column (60 cm depth of the soil) was about 56% after 24 hours of wetting time.

Among the factors which increased the denitrification performance in this experiment was the relatively high percentage of clay and silt in soil A, which increased the anaerobic sites due to the small pores of clay and silt and increased the hydraulic retention time, in addition to the relatively high seasonal temperature as presented in table 5.3, which increased the bacterial activity.

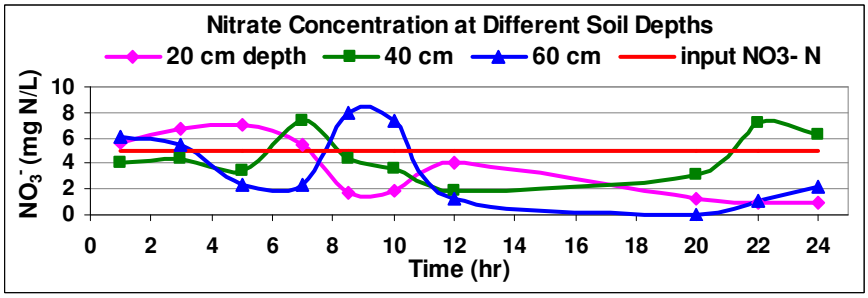

Figure 5.2: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (A) – (Cycle One - First Run - First Wetting Drying schedule).

5.4 EXPERIMENTS BY USING SOIL (B)

Soil (B) was used in the second and third sets of experiments (experiments two to sixteen) in order to study the distribution and the removal efficiency of nitrogen species through SAT column.

The second set of experiments (experiments two to ten) was done by applying the first wetting drying schedule **(24 hours wetting and 48 hours drying time cycles)**, and was three runs every run consisted of three cycles.

The third set of experiments (experiments from eleven to sixteen) was done by applying the second wetting drying schedule **(12 hours wetting and 12 hours drying time cycles)**, and was two runs every run consisted of three cycles.

Conditions of these experiments with respect to temperature degrees during the experiments, the drainage rates and the date of experiments are shown in tables 5.4 to 5.18.

5.4.1 RESULTS OF THE SECOND SET OF EXPERIMENTS: EXPERIMENTS (No. 2 TO 10) USING SOIL (B) – FIRST WETTING DRYING SCHEDULE

5.4.1.1 Ammonia removal:

High ammonia removal was observed during the wetting times of this set of experiments. In the second cycle of the second run (experiment No. 6), ammonia removal efficiency was 73% as shown in figure 5.13.

The relatively long drying time (48 hours) dried the soil to some extent and allowed oxygen to defuse through soil surface and to be stored in the soil creating suitable conditions for nitrification. Dissolved oxygen in the applied synthetic wastewater enhanced also and accelerated the nitrification process. The average of overall initial ammonia removal efficiency during this set of experiments was about 60.5%.

5.4.1.2 Nitrate removal:

No reduction of the initial nitrate concentration was observed during this set experiments, which implies no significant denitrification occurred during the wetting time as shown in figures 5.19 and figure 5.35 (experiments No. 5 and 9 respectively).

The average of drainage rate was relatively high during this set of experiments (about 83 ml/min) because of low percent of silt and clay in soil B as presented in table 5.1, which decreased the average of hydraulic retention time (about 4.5 hours) and the

denitrification performance. Seasonal temperature during this set of experiments was relatively low and was ranging between 6 and 16°C as presented in tables 5.4 to 5.12. The decrease of seasonal temperature reduced the denitrification rate because it reduced the bacterial activity.

High concentrations of nitrates were observed at the three depths of the soil column immediately after the start of wetting times due to nitrates accumulation in the soil column during the drying time, as a result of diffused oxygen through soil surface and oxidation of the adsorbed ammonia to nitrates by nitrification process.

5.4.1.3 Nitrite removal:

Nitrite was formed in the soil solution due to nitrification and denitrification processes, an increase of nitrite concentration was observed at the outlet samples (60 cm depth) in most experiments of the second set.

Nitrite concentration was about 0.8 mg N/L at the end of wetting time in experiments No. 5, 9 and 10 as shown in figures 5.12, 5.24 and 5.28 respectively.

The increase of nitrite concentration during these experiments refers to the relatively short hydraulic retention time as mentioned above.

The overall average of nitrite concentration in the outlet of the soil column (60 cm depth) at the end of wetting times in this set of experiments was about 0.59 mg N/L.

5.4.1.4 Reduction of initial UVA_{254} values:

UV absorbance at 254 nm is used to describe both amount and character of organic chemicals or organic matter in water. The decrease of initial UVA_{254} values in experiment No.10 was 56% at the end of wetting time as shown in figure 5.29 while the decrease of initial UVA_{254} values in experiment No.9 was 5% as shown in figure 5.25.

The reduction of initial UVA_{254} values increases with the increase of ambient temperature which increases the bacterial activity and also it increases with increase of organic matter adsorption.

The following figures show the distribution of ammonia concentration, percentage of ammonia removal, distribution of nitrate concentration, distribution of nitrite

concentration and UVA_{254} values at different soil depths during the second set of experiments (experiments No. 2 to 10).

Tables 5.4 to 5.12 represent the conditions of the experiments with respect to temperature degrees during the experiments, the drainage rates and the date of experiments.

5.4.1.5 Experiment No. 2:

Distribution of nitrogen species through SAT column during **cycle one of the first run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.4: Conditions of experiment No. 2:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 4 Jan. 2013 (afternoon)	Max. 10 Min. 7
Until: 5 Jan. 2013 (afternoon)	Max. 11 Min. 7
Drainage rate	**ml/min**
At the beginning of the wetting time	135
At the middle of the wetting time	90
At the end of the wetting time	65

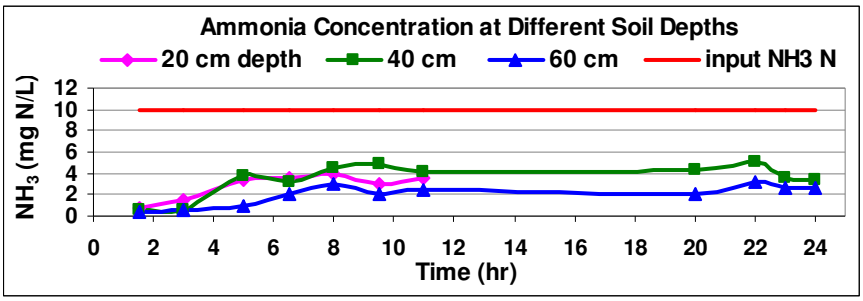

Figure 5.3: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle One - First Run - First Wetting Drying schedule).

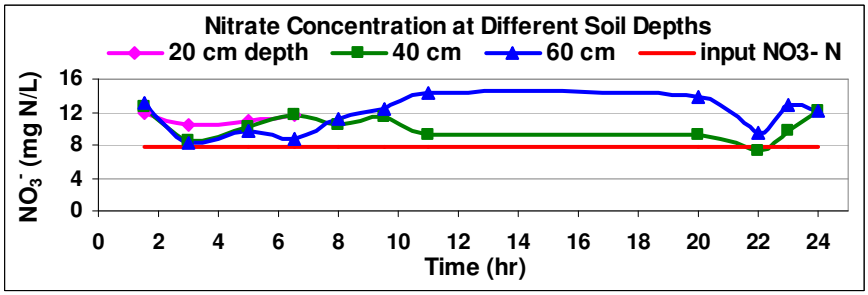

Figure 5.4: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle One - First Run - First Wetting Drying schedule).

5.4.1.6 Experiment No. 3:

Distribution of nitrogen species through SAT column during **cycle two of the first run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.5: Conditions of experiment No. 3:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 7 Jan. 2013 (afternoon)	Max. 11 Min. 8
Until: 8 Jan. 2013 (afternoon)	Max. 9 Min. 6
Drainage rate	**cm^3/min**
At the beginning of the wetting time	125
At the middle of the wetting time	85
At the end of the wetting time	60

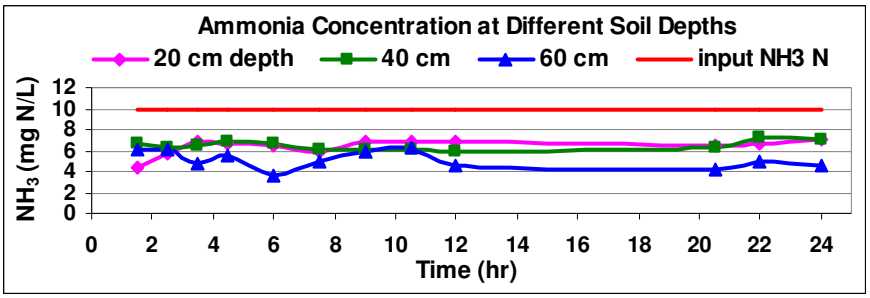

Figure 5.5: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Two - First Run - First Wetting Drying schedule).

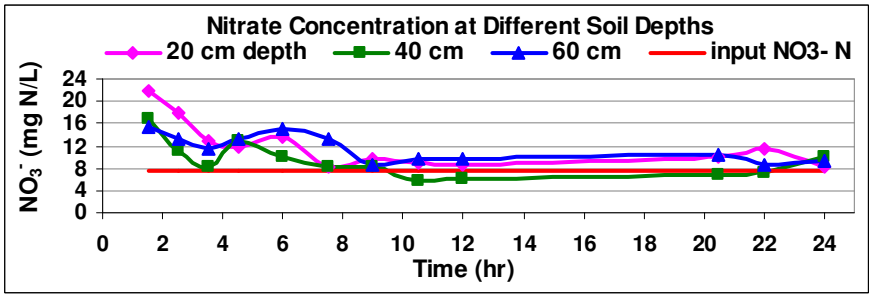

Figure 5.6: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Two - First Run - First Wetting Drying schedule).

5.4.1.7 Experiment No. 4:

Distribution of nitrogen species through SAT column during **cycle three of the first run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.6: Conditions of experiment No. 4:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 10 Jan. 2013 (afternoon)	Max. 12 Min. 7
Until: 11 Jan. 2013 (afternoon)	Max. 13 Min. 8
Drainage rate	**ml/min**
At the beginning of the wetting time	130
At the middle of the wetting time	90
At the end of the wetting time	65

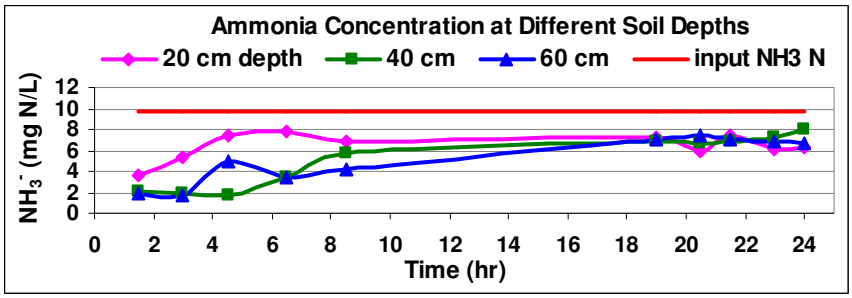

Figure 5.7: Distribution of Ammonia Concentration at Different Soils Depth Using Soil (B) – (Cycle Three - First Run - First Wetting Drying schedule).

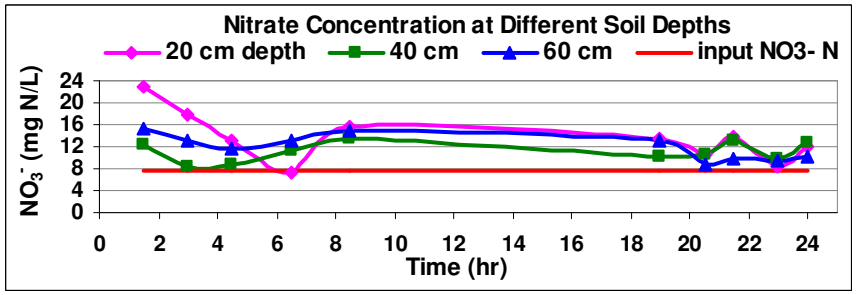

Figure 5.8: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Three - First Run - First Wetting Drying schedule).

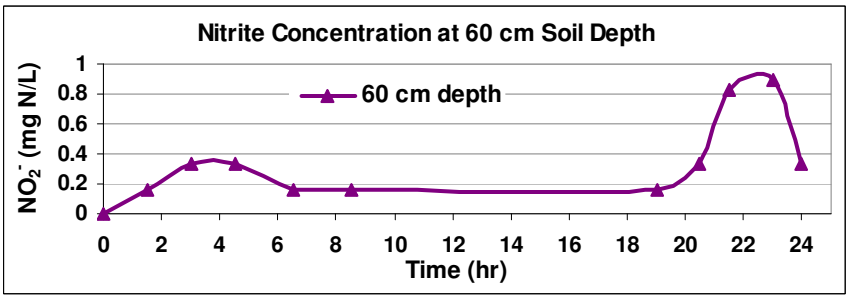

Figure 5.9: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Three - First Run - First Wetting Drying schedule).

5.4.1.8 Experiment No. 5:

Distribution of nitrogen species through SAT column during **cycle one of the second run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.7: Conditions of experiment No. 5:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 13 Jan. 2013 (afternoon)	Max. 14 Min. 9
Until: 14 Jan. 2013 (afternoon)	Max. 14 Min. 8
Drainage rate	**ml/min**
At the beginning of the wetting time	125
At the middle of the wetting time	85
At the end of the wetting time	60

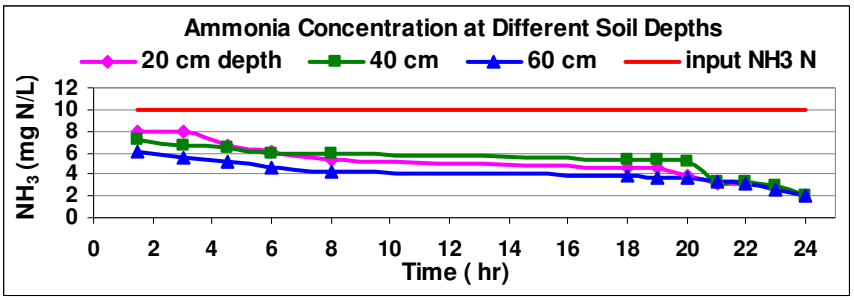

Figure 5.10: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle One – Second Run - First Wetting Drying schedule).

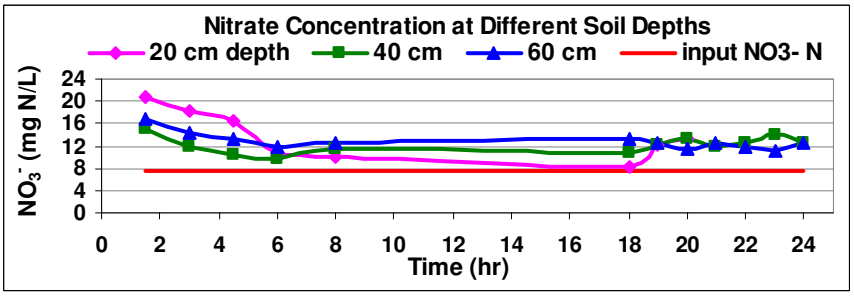

Figure 5.11: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle One – Second Run - First Wetting Drying schedule).

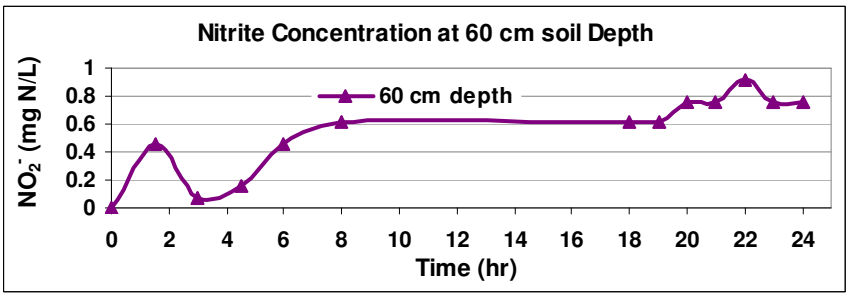

Figure 5.12: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle One – Second Run - First Wetting Drying schedule).

5.4.1.9 Experiment No. 6:

Distribution of nitrogen species through SAT column during **cycle two of the second run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.8: Conditions of the experiment No. 6:

Date of the experiment (wetting time)	Temperature Degree (C°)
Start: 16 Jan. 2013 (afternoon)	Max. 16 Min. 8
Until: 17 Jan. 2013 (afternoon)	Max. 17 Min. 9
Drainage rate	**ml/min**
At the beginning of the wetting time	100
At the middle of the wetting time	70
At the end of the wetting time	50

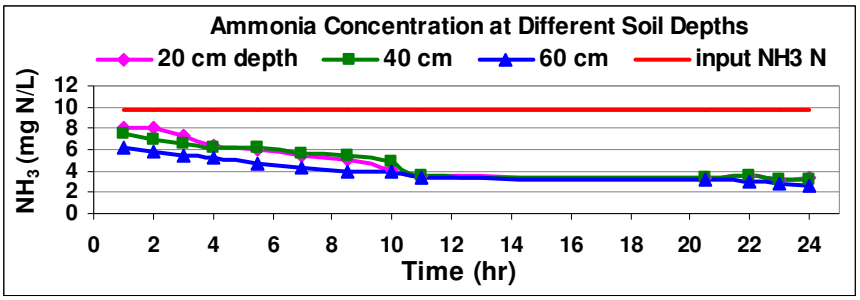

Figure 5.13: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – Second Run - First Wetting Drying schedule).

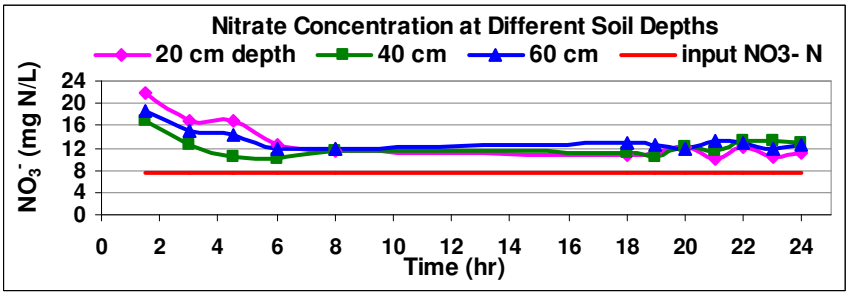

Figure 5.14: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – Second Run - First Wetting Drying schedule).

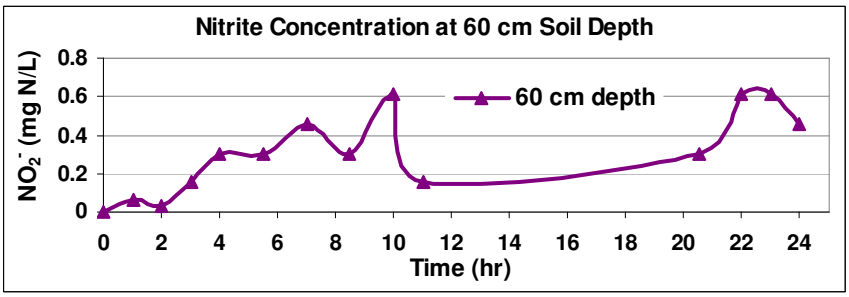

Figure 5.15: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Two – Second Run - First Wetting Drying schedule).

5.4.1.10 Experiment No. 7:

Distribution of nitrogen species through SAT column during **cycle three of the second run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.9: Conditions of experiment No. 7:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 19 Jan. 2013 (afternoon)	Max. 17 Min. 9
Until: 20 Jan. 2013 (afternoon)	Max. 17 Min. 10
Drainage rate	**ml/min**
At the beginning of the wetting time	90
At the middle of the wetting time	55
At the end of the wetting time	40

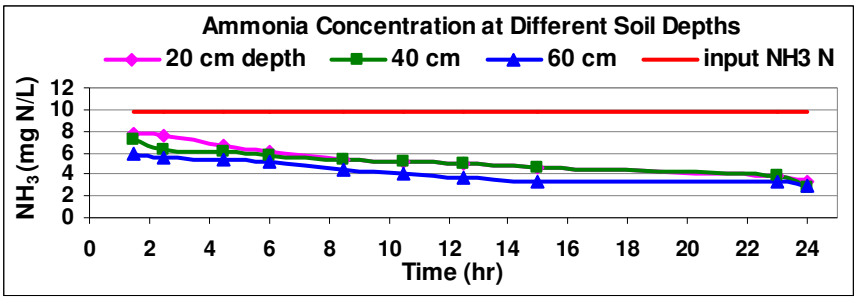

Figure 5.16: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – Second Run - First Wetting Drying schedule).

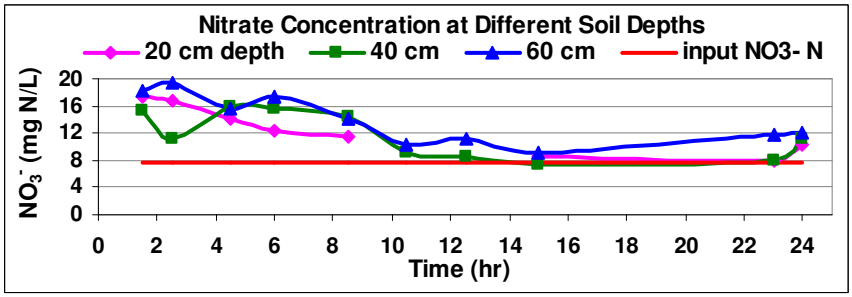

Figure 5.17: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – Second Run - First Wetting Drying schedule).

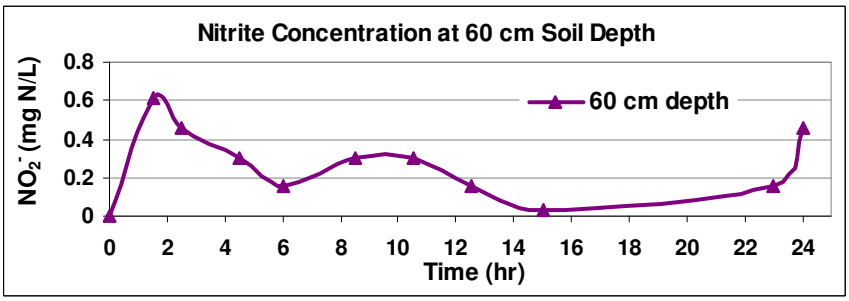

Figure 5.18: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Three – Second Run - First Wetting Drying schedule).

5.4.1.11 Experiment No. 8:

Distribution of nitrogen species through SAT column during **cycle one of the third run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.10: Conditions of experiment No. 8:

Date of the experiment (wetting time)	Temperature Degree (°C)	
Start: 26 Jan. 2013 (afternoon)	Max. 15	Min. 8
Until: 27 Jan. 2013 (afternoon)	Max. 15	Min. 7
Drainage rate	**ml/min**	
At the beginning of the wetting time	100	
At the middle of the wetting time	75	
At the end of the wetting time	55	

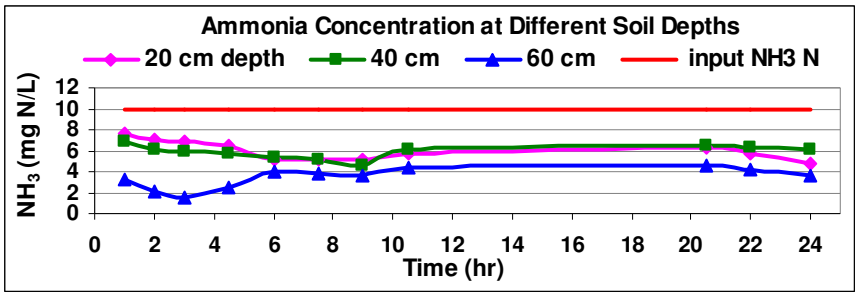

Figure 5.19: Distribution of Ammonia Concentration at Different Soil Depth Using Soil (B) – (Cycle One – Third Run - First Wetting Drying schedule).

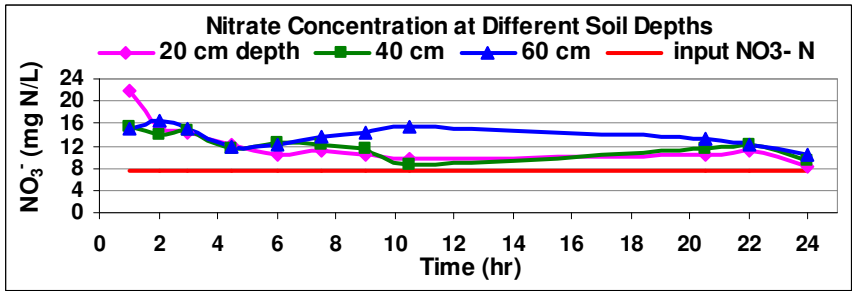

Figure 5.20: Distribution of Nitrate Concentration at Different Soil Depth Using Soil (B) – (Cycle One – Third Run - First Wetting Drying schedule).

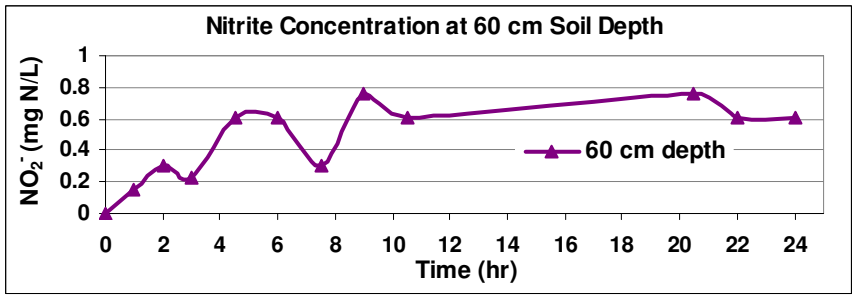

Figure 5.21: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle One – Third Run - First Wetting Drying schedule).

5.4.1.12 Experiment No. 9:

Distribution of nitrogen species through SAT column during **cycle two of the third run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.11: Conditions of experiment No. 9:

Date of the experiment (wetting time)	**Temperature Degree (°C)**	
Start: 29 Jan. 2013 (afternoon)	Max. 12	Min. 7
Until: 30 Jan. 2013 (afternoon)	Max. 12	Min. 7
Drainage rate	**ml/min**	
At the beginning of the wetting time	90	
At the middle of the wetting time t	80	
At the end of the wetting time	60	

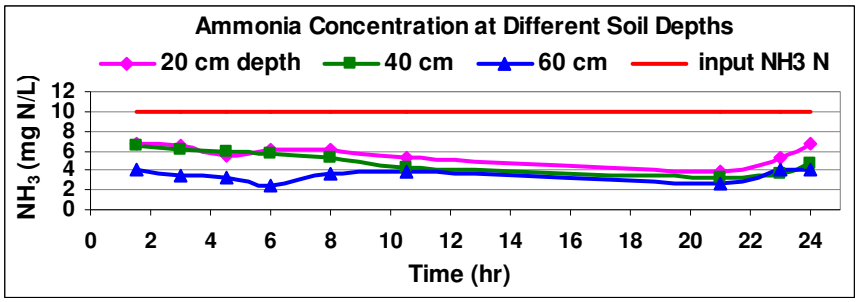

Figure 5.22: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – Third Run - First Wetting Drying schedule).

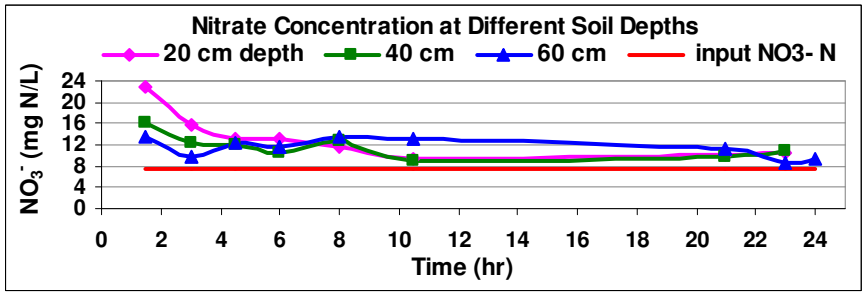

Figure 5.23: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – Third Run - First Wetting Drying schedule).

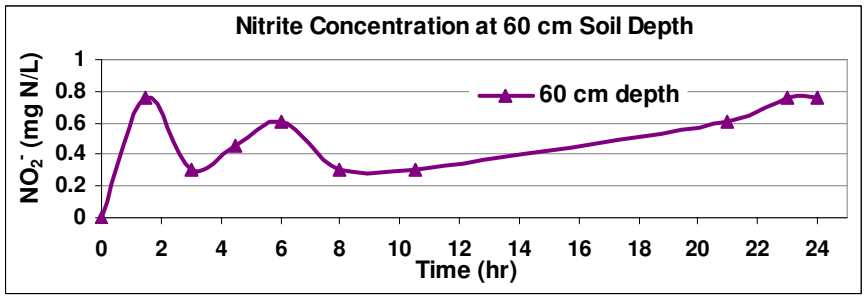

Figure 5.24: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Two – Third Run - First Wetting Drying schedule).

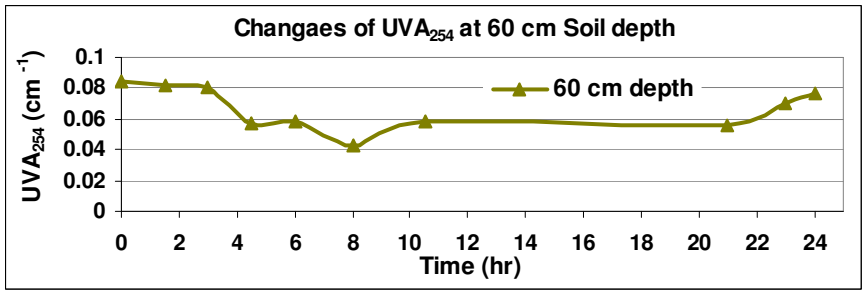

Figure 5.25: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle Two – Third Run - First Wetting Drying schedule).

5.4.1.13 Experiment No. 10:

Distribution of nitrogen species through SAT column during **cycle three of the third run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.12: Conditions of experiment No. 10:

Date of the experiment (wetting time)	Temperature Degree (°C)	
Start: 1 Feb. 2013 (afternoon)	Max. 14	Min. 9
Until: 2 Feb. 2013 (afternoon)	Max. 15	Min. 10
Drainage rate	**ml/min**	
At the beginning of the wetting time	60	
At the middle of the wetting time	90	
At the end of the wetting time	100	

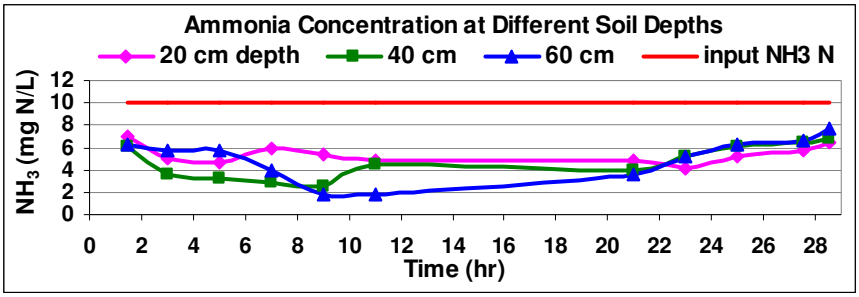

Figure 5.26: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – Third Run - First Wetting Drying schedule).

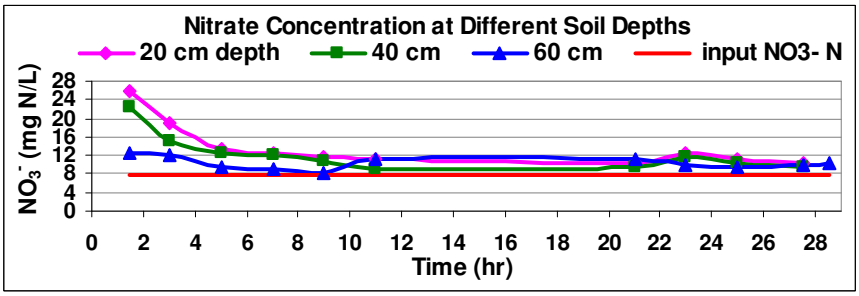

Figure 5.27: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – Third Run - First Wetting Drying schedule).

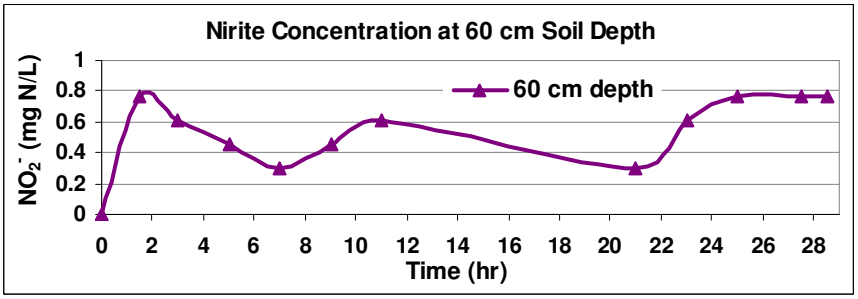

Figure 5.28: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Three – Third Run - First Wetting Drying schedule).

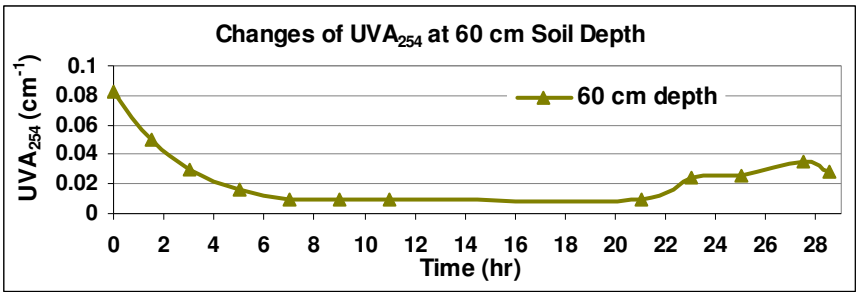

Figure 5.29: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle Three – Third Run - First Wetting Drying schedule).

5.4.2 RESULS OF THE THIRD SET OF EXPERIMENTS: EXPERIMENTS (No. 11 TO 16) USING SOIL (B) – SECOND WETTING DRYING SCHEDULE

5.4.2.1 Ammonia removal:

The drying time of this set of experiments was short (about 12 hours) and the average of seasonal temperature rang was rather low. Ammonia removal was high during this set of experiments and the average of overall reduction efficiency of the initial ammonia concentration was about 61%.

The soil did not dry enough and remained moist during the drying time of this set of experiments which reduced the diffusion of oxygen from the soil surface. But it is expected that the applied synthetic wastewater was the source of the dissolved oxygen for nitrification process.

In experiments No. 15 and No.16 ammonia removal was about 80% at 60 cm soil depth as shown in figures 5.46 and 5.50 respectively, while ammonia removal was about 40% at 20 cm soil depth as shown in the same figures, which probably attributed to the low drainage rate and to the increasing of nitrification rate near the exit of the soil column where aerobic conditions may exist.

5.4.2.2 Nitrate removal:

Sseasonal temperature increased slightly during this set of experiments compared to the temperature rate during the second set of experiments, but remained relatively low and ranging between 8 and 17°C as presented in tables 5.13 to 5.18.

The average of nitrates removal efficiency was also very low during this set of experiments (about 2%). In experiment No.13 as shown in figure 5.39, and in experiment No. 14 as shown in figure 5.43, the efficiency of initial nitrate removal was 10% and 5% respectively which attributed to the low average of drainage rates as presented in tables 5.15 and 5.16 respectively, and to the increase of hydraulic retention time which enhanced the denitrification rate to some extent.

5.4.2.3 Nitrite removal:

As mentioned above, it was observed high nitrification rates in this set of experiments at 60 cm depth of the soil in most experiments of this set. And also high reduction of the formed nitrite at this depth was observed in most experiments of this set, which refers to complete nitrification processes due to the low average of drainage rate.
In the second cycle of the first run (experiment No. 12) as shown figure 5.36 the concentration of nitrite at the outlet was 0.15 mg N/L and the average of drainage rate in this experiment was about 40 ml/min. The average of nitrite concentration at the end of wetting times in this set of experiments was low and about 0.3 mg N/L.

5.4.2.4 Reduction of initial UVA_{254} values:

Low reduction of initial values of UVA_{254} were observed during this set of experiments as shown in figure 5.45 (experiment No. 14), where the UVA_{254} initial value reduction was about 30% at the end of wetting time. And the average of overall reduction of initial UVA_{254} values was about 36%, which implies low biodegradation of dissolved organic carbon and low efficiency of denitrification rate due to the low prevailed temperature degrees and low bacterial activity.

The following figures show the distribution of ammonia concentration, percentage of ammonia removal, distribution of nitrate concentration, distribution of nitrite concentration and UVA_{254} values at different soil depths during the third set of experiments (experiments No. 11 to 16). Tables 5.13 to 5.18 represent the conditions of the experiments with respect to temperature degrees during the experiments, the drainage rates and the date of experiments.

5.4.2.5 Experiment No. 11:

Distribution of nitrogen species through SAT column during **cycle one of the first run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.13: Conditions of experiment No. 11:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 9 Feb. 2013 (afternoon)	Max. 16 Min. 8
Drainage rate	**ml/min**
At the beginning of the wetting time	65
At the middle of the wetting time	85
At the end of the wetting time	60

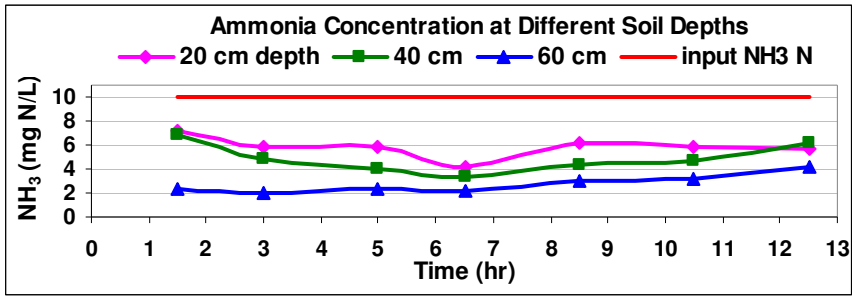

Figure 5.30: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle One – First Run - Second Wetting Drying schedule).

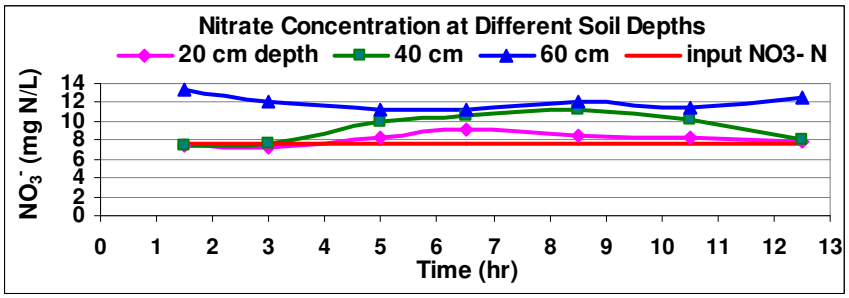

Figure 5.31: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle One – First Run - Second Wetting Drying schedule).

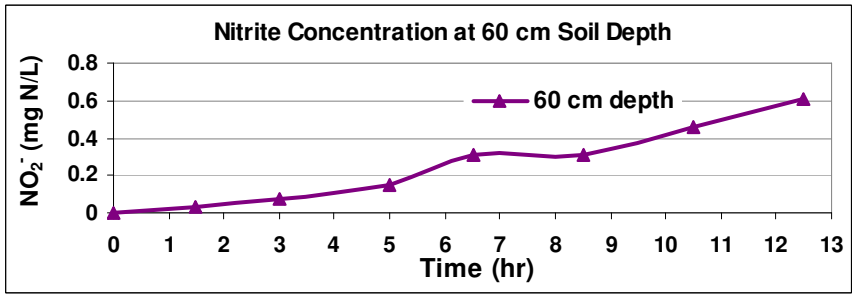

Figure 5.32: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle One – First Run - Second Wetting Drying schedule).

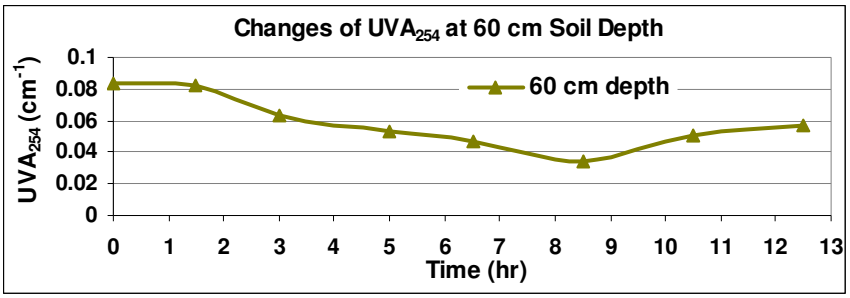

Figure 5.33: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle One – First Run - Second Wetting Drying schedule).

5.4.2.6 Experiment No. 12:

Distribution of nitrogen species through SAT column during **cycle two of the first run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.14: Conditions of experiment No. 12:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 10 Feb. 2013 (afternoon)	Max. 16 Min. 11
Drainage rate	**ml/min**
At the beginning of the wetting time	40
At the middle of the wetting time	60
At the end of the wetting time	40

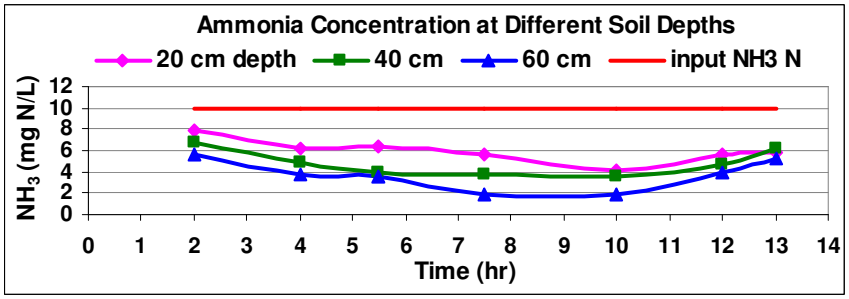

Figure 5.34: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – First Run - Second Wetting Drying schedule).

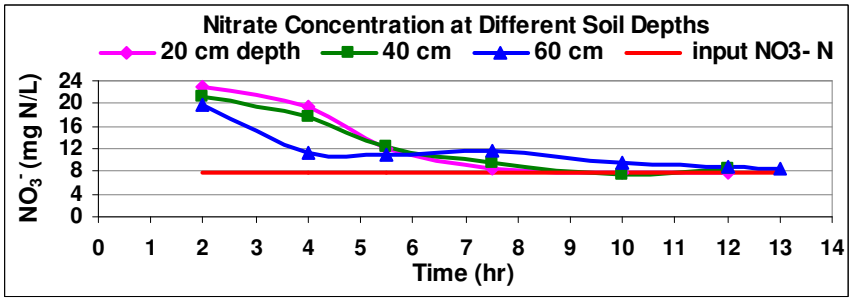

Figure 5.35: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Two - First Run - Second Wetting Drying schedule).

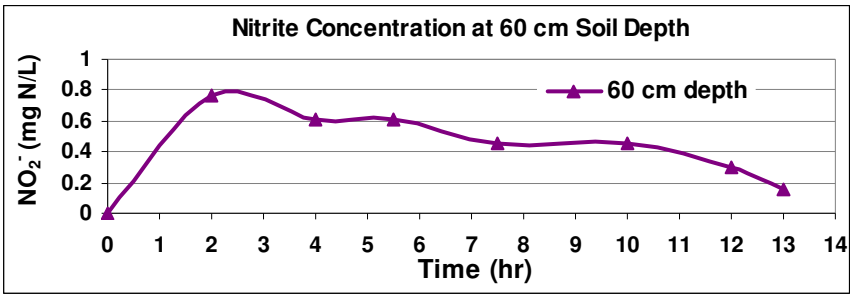

Figure 5.36: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Two – First Run - Second Wetting Drying schedule).

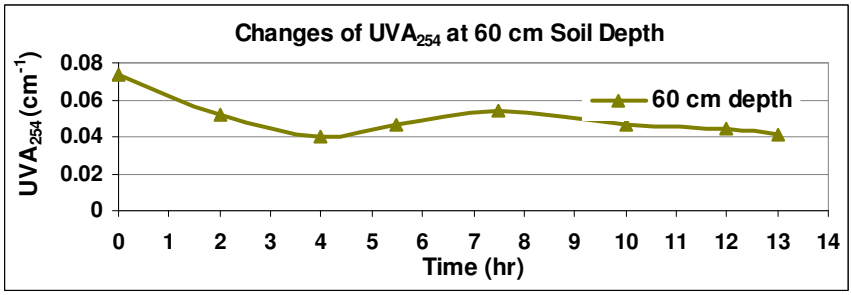

Figure 5.37: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle Two – First Run - Second Wetting Drying schedule).

5.4.2.7 Experiment No. 13:

Distribution of nitrogen species through SAT column during **cycle three of the first run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.15: Conditions of experiment No. 13:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 11 Feb. 2013 (afternoon)	Max. 17 Min12
Drainage rate	**ml/min**
At the beginning of the wetting time	40
At the middle of the wetting time	45
At the end of the wetting time	30

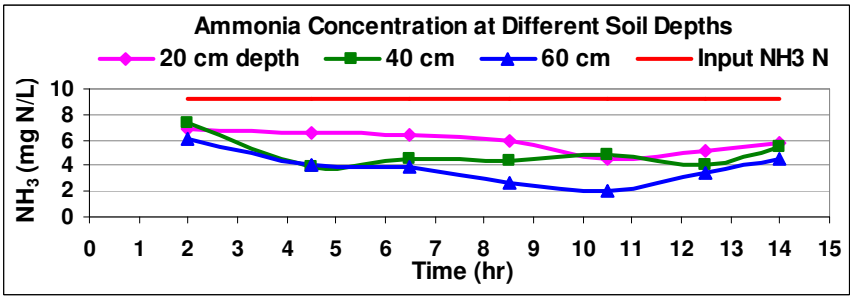

Figure 5.38: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – First Run - Second Wetting Drying schedule).

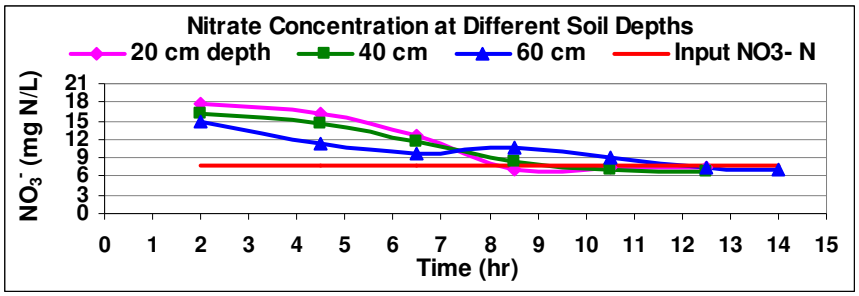

Figure 5.39: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – First Run - Second Wetting Drying schedule).

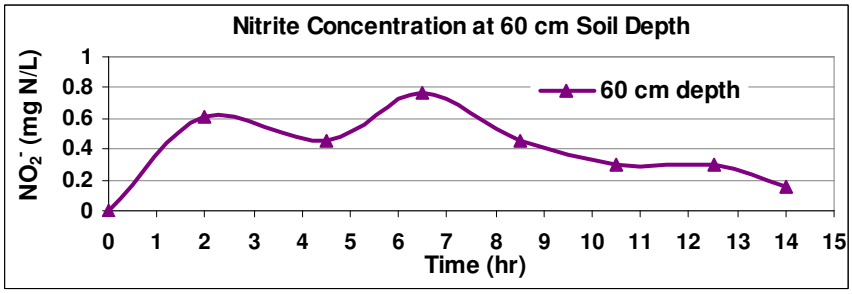

Figure 5.40: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle One – First Run - Second Wetting Drying schedule).

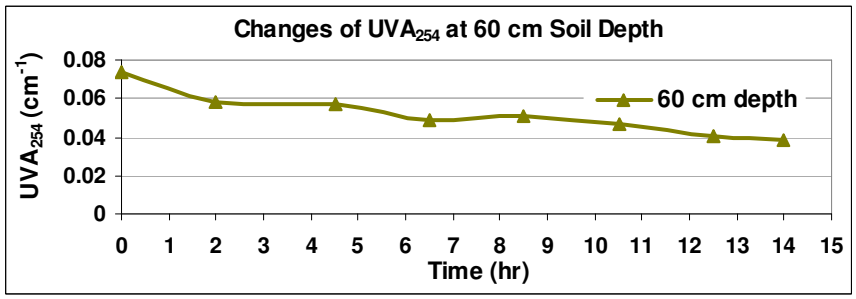

Figure 5.41: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle Three – First Run - Second Wetting Drying schedule).

5.4.2.8 Experiment No. 14:

Distribution of nitrogen species through SAT column during **cycle one of the second run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.16: Conditions of experiment No. 14:

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 16 Feb 2013 (afternoon)	Max. 17 Min. 11
Drainage rate	**ml/min**
At the beginning of the wetting time	60
At the middle of the wetting time	55
At the end of the wetting time	35

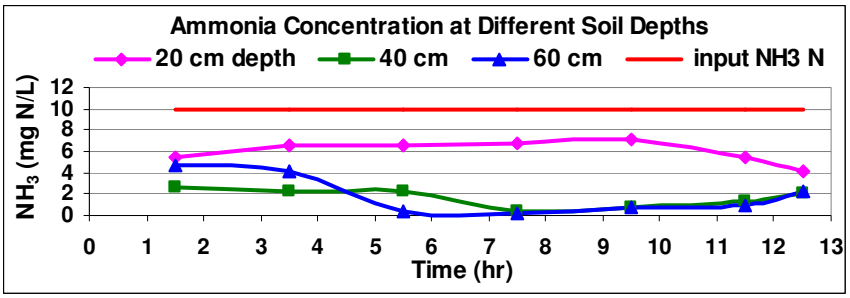

Figure 5.42: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle One – Second Run - Second Wetting Drying schedule).

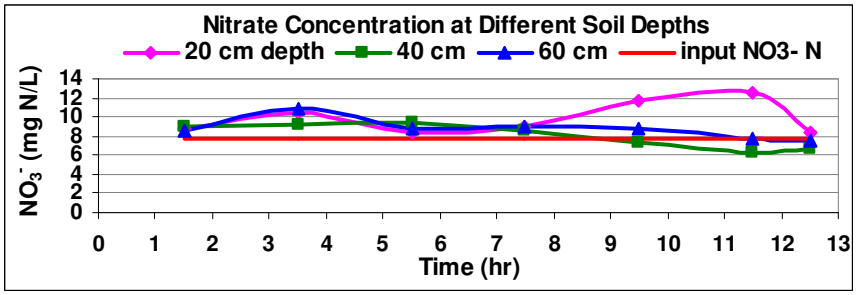

Figure 5.43: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle One – Second Run - Second Wetting Drying schedule).

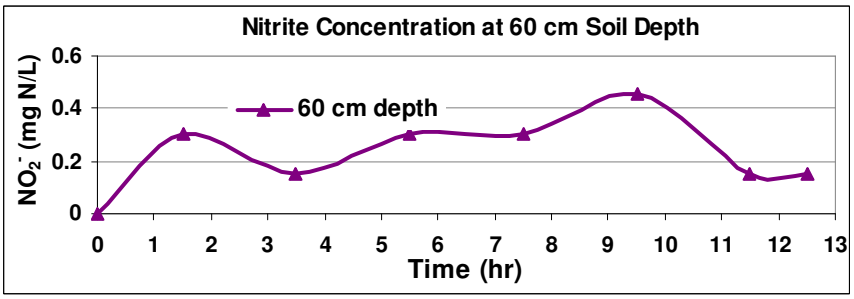

Figure 5.44: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle One – Second Run - Second Wetting Drying schedule).

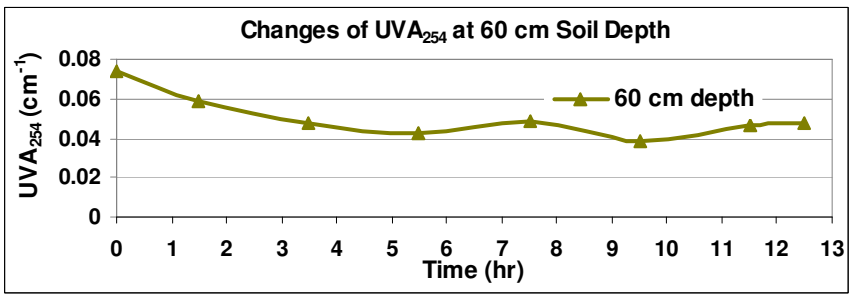

Figure 5.45: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle One – Second Run - Second Wetting Drying schedule).

5.4.2.9 Experiment No. 15:

Distribution of nitrogen species through SAT column during **cycle two of the second run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.17: Conditions of experiment No. 15:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 17 Feb. 2013 (afternoon)	Max. 15 Min. 10
Drainage rate	**ml/min**
At the beginning of the wetting time	20
At the middle of the wetting time	18
At the end of the wetting time	14

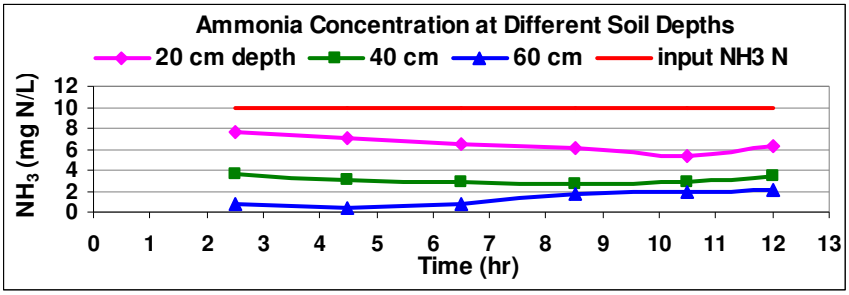

Figure 5.46: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – Second Run - Second Wetting Drying schedule).

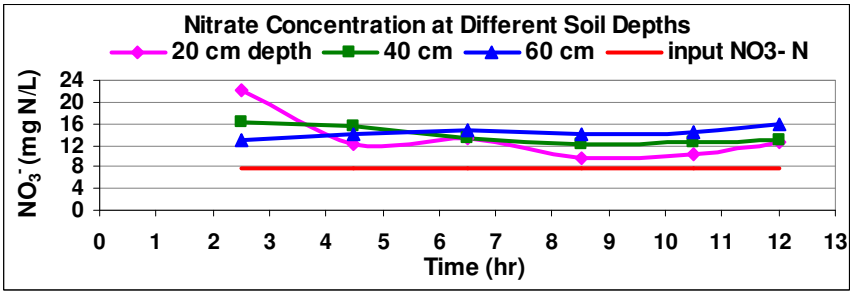

Figure 5.47: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Two – Second Run - Second Wetting Drying schedule).

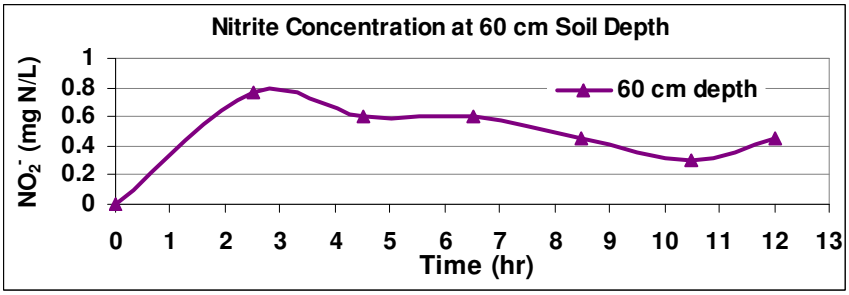

Figure 5.48: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (B) – (Cycle Two – Second Run - Second Wetting Drying schedule).

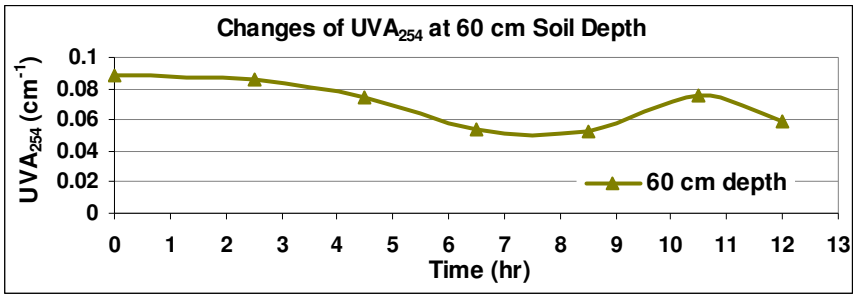

Figure 5.49: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (B) – (Cycle Two – Second Run - Second Wetting Drying schedule).

5.4.2.10 Experiment No. 16:

Distribution of nitrogen species through SAT column during **cycle Three of the second run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.18: Conditions of experiment No. 16**:**

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 20 Feb. 2013 (afternoon)	Max. 15 Min. 10
Drainage rate	**ml/min**
At the beginning of the wetting time	20
At the middle of the wetting time	18
At the end of the wetting time	14

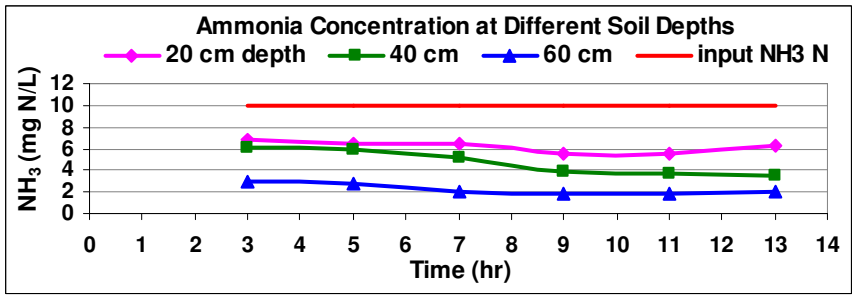

Figure 5.50: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

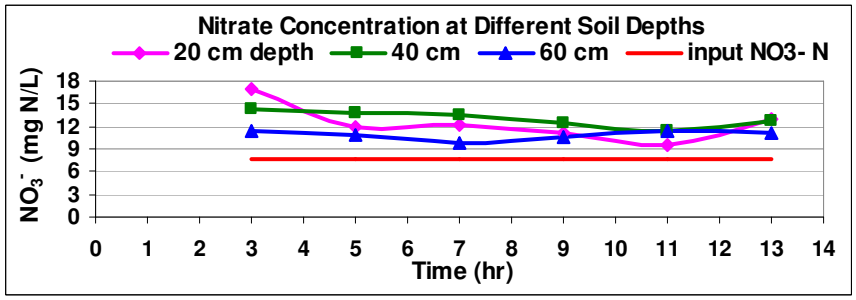

Figure 5.51: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (B) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

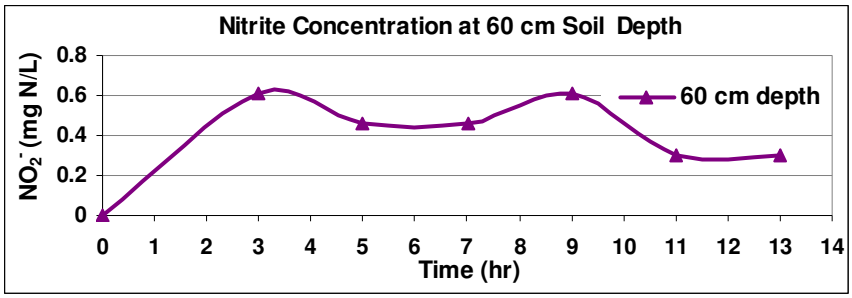

Figure 5.52: Distribution of Nitrite Concentration at 60 cm Soil Depth
Using Soil (B) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

5.5 EXPERIMENTS BY USING SOIL (C)

Soil (C) was used in the fourth and the fifth set of experiments (experiments seventeen to thirty) in order to study the distribution and the removal efficiency of nitrogen species through SAT column. The fourth set of experiments (experiments seventeen to twenty four) was done by applying the first wetting drying schedule **(24 hours wetting and 48 hours drying time cycles),** and was three runs, the first and the third runs consisted of three cycles while the second run consisted of two cycles . The fifth set of experiments (experiments twenty four to thirty) was done by applying the second wetting drying schedule **(12 hours wetting and 12 hours drying time cycles),** and was two runs every run was consisted of three cycles.

Conditions of these experiments with respect to temperature degrees during the experiments, the drainage rates and the date of experiments are shown in tables 5.19 to 5.32.

5.5.1 RESULTS OF THE FOURTH SET OF EXPERIMENTS: EXPERIMENTS (No. 17 TO 24) USING SOIL (C) – FIRST WETTING DRYING SCHEDULE

5.5.1.1 Ammonia removal:

A high reduction of initial ammonia was observed during this set of experiments because of long drying time (two days) and high seasonal temperature which approximately dried the soil and allowed oxygen to defuse through the soil which created an aerobic conditions suitable for high nitrification rates. In the third cycle of

the first run (experiment No.19) the efficiency of ammonia removal was about 86% as shown in figure 61, while it was about 25% in cycle three of the third run (experiment No. 24) as shown in figure 5.81.

In general, the overall average of initial ammonia removal during this set of experiments was 60.3%. The average of drainage rate was high during this set of experiments (about 109 ml/min) and the hydraulic retention times time was short and about 3.4 hours because of the low composition of clay and silt in soil C, which reduced the average of initial ammonia removal to some extent.

5.5.1.2 Nitrate removal:

Seasonal temperature has been increased significantly during this set of experiments and it was ranging between 13 and 34°C, which increased the nitrate removal and the denitrification rates during this set of experiments.

In cycle one of the third run (experiment No. 22) temperature was high and was ranging between 15 and 34°C as shown in table 5.24 and the initial nitrates reduction efficiency at the outlet of soil column (60 cm depth) was about 25% as shown in figure 5.74.

In the third cycle of the third run (experiment No. 24) temperature was ranging between 16 and 29°C as shown in table 5.26 and the initial nitrates reduction efficiency at the outlet of soil (60 cm soil depth) was about 19% as shown in figure 5.82. But in cycle two of the third run (experiment No. 23) temperature was decreased to some extent and it was ranging between 13 and 17°C as shown in table 5.25, and so no significant reduction of initial nitrates was observed as shown in figure 5.78 due to the decrease of temperature.

In general, the average of overall input nitrates removal during this set of experiments was about 15%. The short hydraulic retention times time during this set of experiments decreased the average of nitrate removal efficiency to some extent.

5.5.1.3 Nitrite removal:

In general, the average of the formed nitrite concentration at the end of wetting times during this set of experiments was about 0.55 mg N/L duo to the short average of hydraulic retention time as mentioned above.

In the third cycle of the first run (experiment No. 19) ammonia removal was 84% as shown in figure 5.61 and the concentration of nitrite at the end of wetting time was 0.16 mg N/L as shown in figure 5.63.

While in the second cycle of the second run (experiment No. 21) ammonia removal was 40% as shown in figure 5.69, and the concentration of nitrite at the end of wetting time was 0.61 mg N/L as shown in figure 5.71, which implies that nitrite reduction is accompanying to ammonia reduction.

5.5.1.4 Reduction of initial UVA_{254} values:

A high changes in the UVA_{254} distribution values were observed in most experiments of this set, especially when temperature was relatively high which indicate high bacterial activity.

In experiment number 24, the overall reduction of initial UVA_{254} value was more than 95% at the end of wetting time as shown in figure 5.84, and the average of overall reduction of initial UVA_{254} values was about 61% during this set of experiments which implies high bacterial activity and high DOC biodegradation.

The following figures show the distribution of ammonia concentration, percentage of ammonia removal, distribution of nitrate concentration, distribution of nitrite concentration and UVA_{254} values at different soil depths during the fourth set of experiments (experiments No. 17 to 24). Tables 5.19 to 5.26 represent the conditions of the experiments with respect to temperature degrees during the experiments, the drainage rates and the date of experiments.

5.5.1.5 Experiment No. 17:

Distribution of nitrogen species through SAT column during **cycle one of the first run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.19: Conditions of experiment No. 17:

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 26 Feb. 2013 (afternoon)	Max. 25 Min. 15
Until: 27 Feb. 2013 (afternoon)	Max. 21 Min. 14
Drainage rate	**cm^3/min**
At the beginning of the wetting time	350
At the middle of the wetting time	80
At the end of the wetting time	30

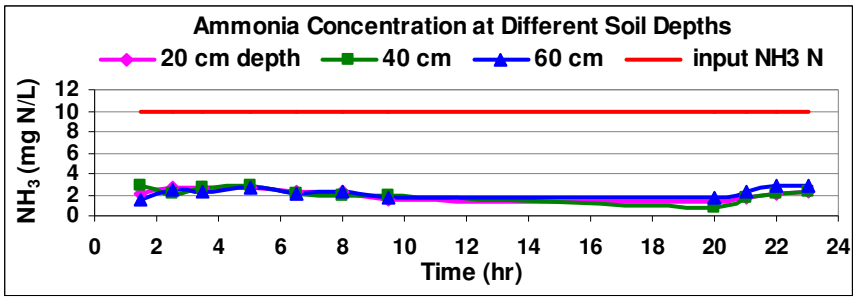

Figure 5.53: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle One – First Run - First Wetting Drying Schedule).

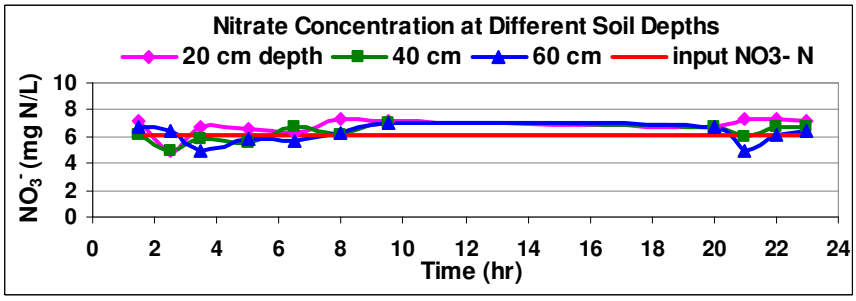

Figure 5.54: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle One – First Run - First Wetting Drying Schedule).

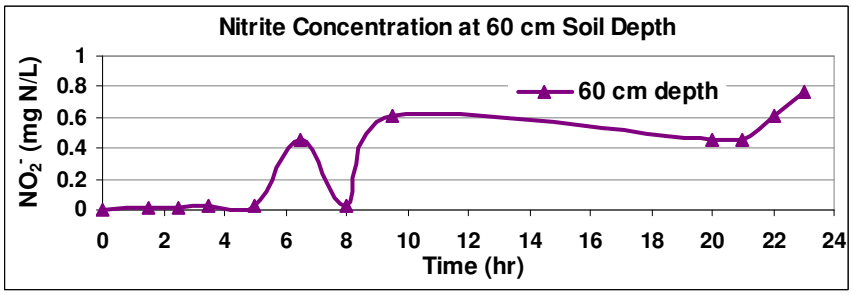

Figure 5.55: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle One – First Run - First Wetting Drying Schedule).

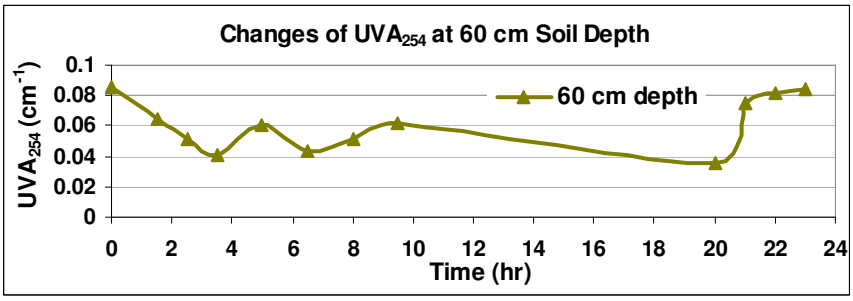

Figure 5.56: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle One – First Run - First Wetting Drying Schedule).

5.5.1.6 Experiment No. 18:

Distribution of nitrogen species through SAT column during **cycle two of the first run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.20: Conditions of experiment No. 18:

Date of the experiment (wetting time)	Temperature Degree (°C)	
Start: 1 March 2013 (afternoon)	Max. 22	Min. 14
Until: 2 March 2013 (afternoon)	Max. 25	Min. 15
Drainage rate	**cm^3/min**	
At the beginning of the wetting time	230	
At the middle of the wetting time	80	
At the end of the wetting time	20	

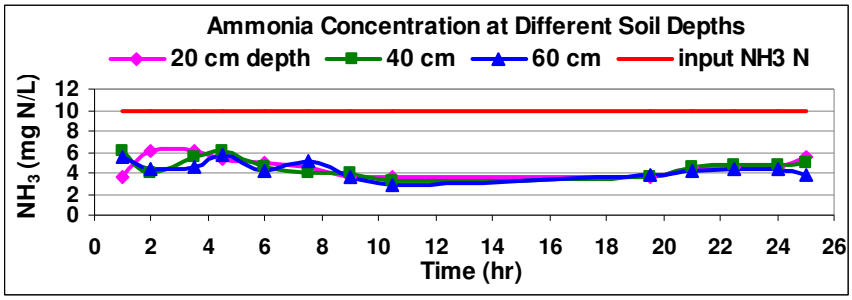

Figure 5.57: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – First Run - First Wetting Drying Schedule).

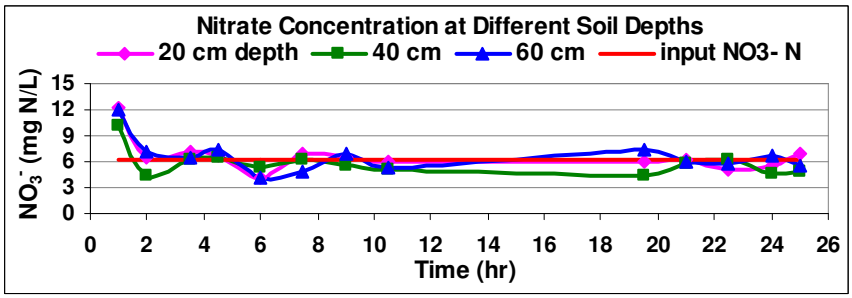

Figure 558: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – First Run - First Wetting Drying Schedule).

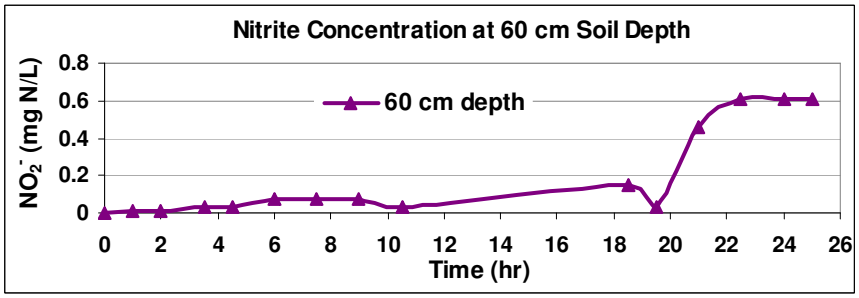

Figure 5.59: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Two – First Run - First Wetting Drying Schedule).

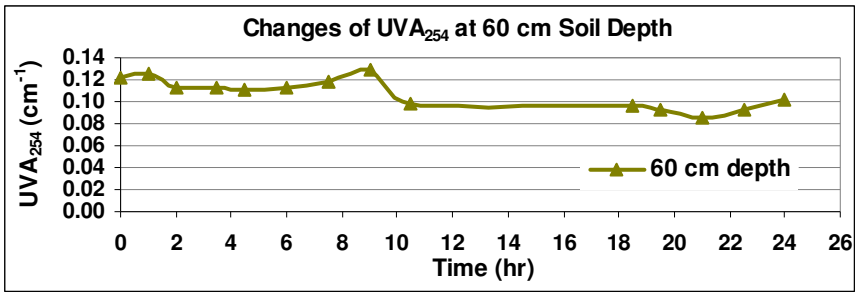

Figure 5.60: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Two – First Run - First Wetting Drying Schedule).

5.5.1.7 Experiment No. 19:

Distribution of nitrogen species through SAT column during **cycle three of the first run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.21: Conditions of the experiment No. 19

Date of the experiment (wetting time)	Temperature Degree (°C)	
Start: 4 March 2013 (afternoon)	Max. 19	Min. 13
Until: 5 March 2013 (afternoon)	Max. 18	Min. 13
Drainage rate	**cm^3/min**	
At the beginning of the wetting time	280	
At the middle of the wetting time	75	
At the end of the wetting time	15	

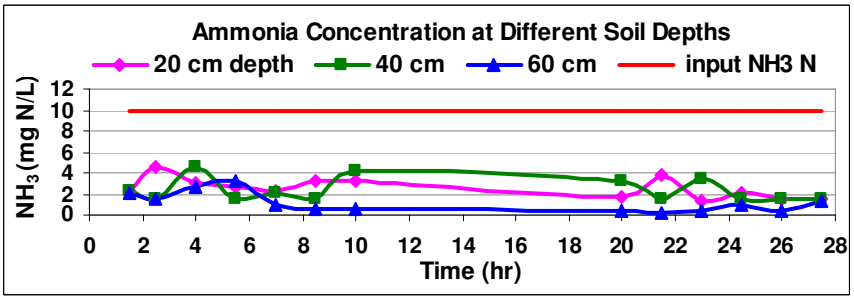

Figure 5.61: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – First Run - First Wetting Drying Schedule).

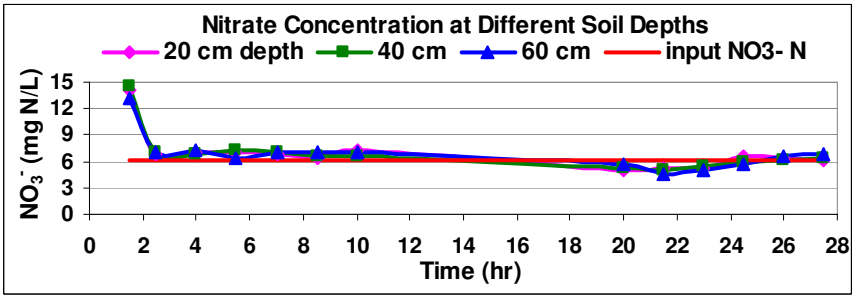

Figure 5.62: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – First Run - First Wetting Drying Schedule).

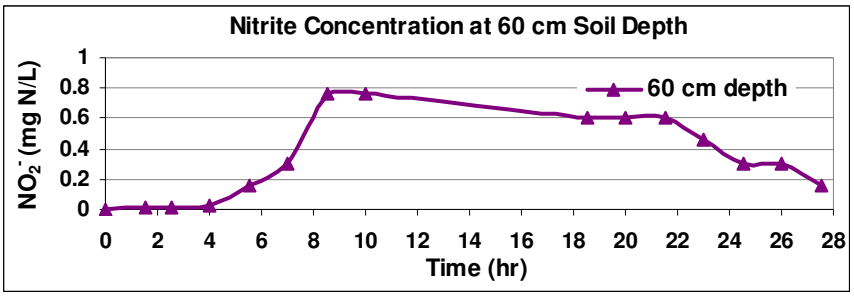

Figure 5.63: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Three – First Run - First Wetting Drying Schedule).

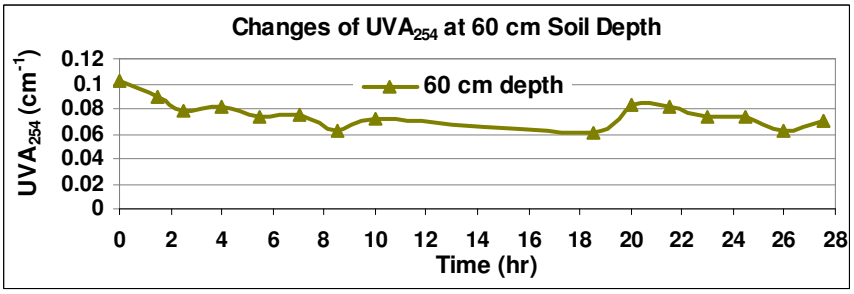

Figure 5.64: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Three – First Run - First Wetting Drying Schedule).

5.5.1.8 Experiment No. 20:

Distribution of nitrogen species through SAT column during **cycle one of the second run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.22: Conditions of experiment No. 20

Date of the experiment (wetting time)	**Temperature Degree (°C)**	
Start: 8 March 2013 (afternoon)	Max. 25	Min. 13
Until: 9 March 2013 (afternoon)	Max. 23	Min. 12
Drainage rate	**cm^3/min**	
At the beginning of the wetting time	170	
At the middle of the wetting time	40	
At the end of the wetting time	25	

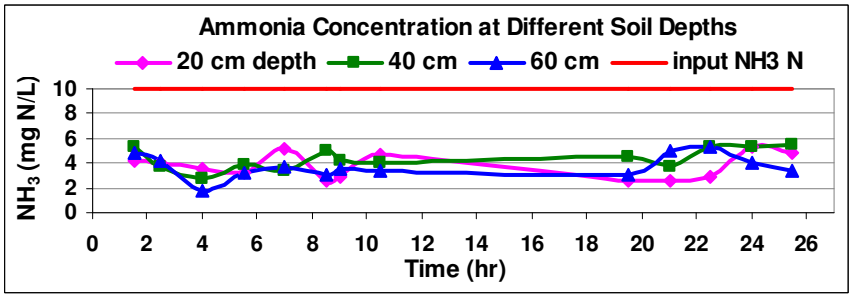

Figure 5.65: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle One – Second Run - First Wetting Drying Schedule).

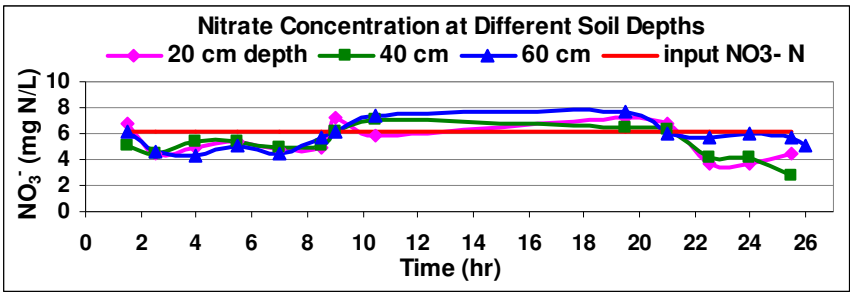

Figure 5.66: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle One – Second Run - First Wetting Drying Schedule).

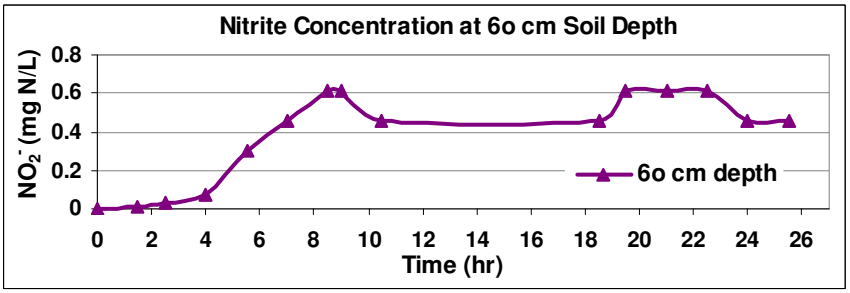

Figure 5.67: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle One – Second Run - First Wetting Drying Schedule).

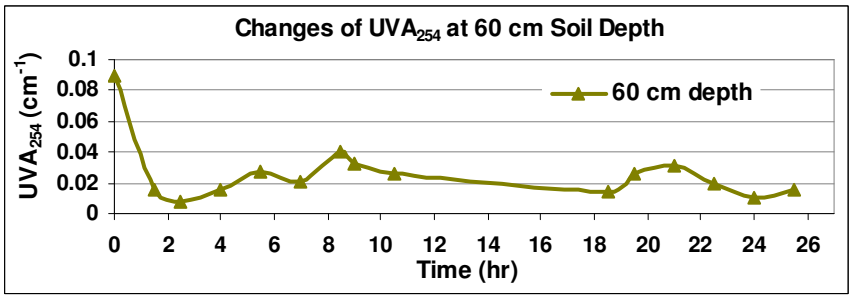

Figure 5.68: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle One – Second Run - First Wetting Drying Schedule).

5.5.1.9 Experiment No. 21:

Distribution of nitrogen species through SAT column during **cycle two of the second run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.23: Conditions of experiment No. 21

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 11 March 2013 (afternoon)	Max. 26 Min. 18
Until: 12 March 2013 (afternoon)	Max. 29 Min. 18
Drainage rate	**cm^3/min**
At the beginning of the wetting time	220
At the middle of the wetting time	90
At the end of the wetting time	35

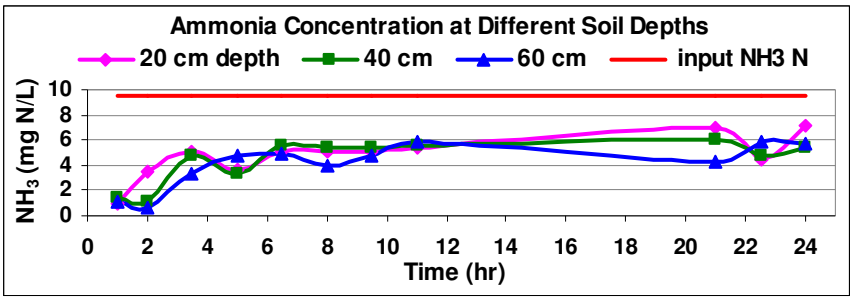

Figure 5.69: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – Second Run - First Wetting Drying Schedule).

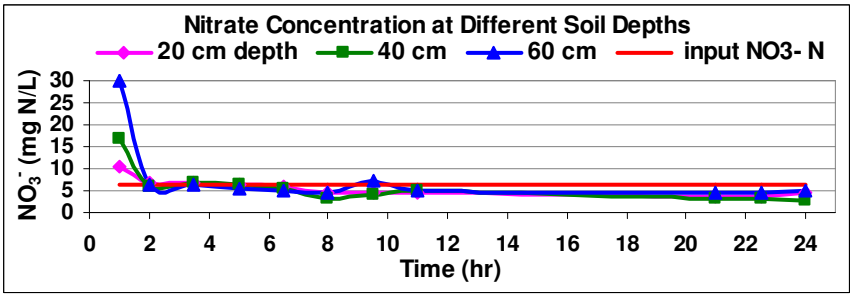

Figure 5.70: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – Second Run - First Wetting Drying Schedule).

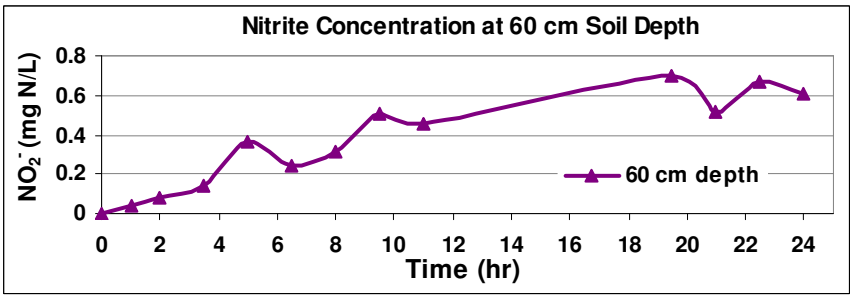

Figure 5.71: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Two – Second Run - First Wetting Drying Schedule).

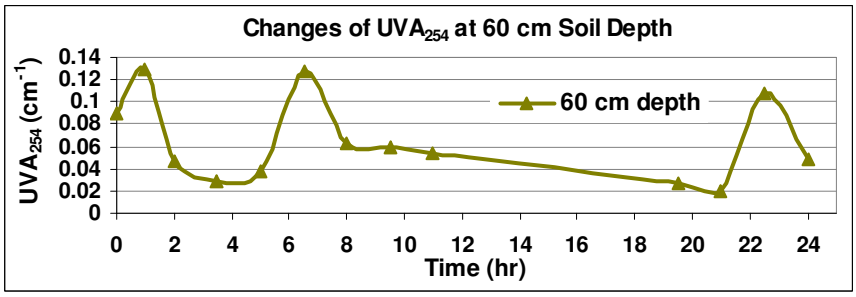

Figure 5.72: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Two – Second Run - First Wetting Drying Schedule).

5.5.1.10 Experiment No. 22:

Distribution of nitrogen species through SAT column during **cycle one of the third run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.24: Conditions of experiment No. 22:

Date of the experiment (wetting time)	Temperature Degree (°C)	
Start: 15 March 2013 (afternoon)	Max. 34	Min. 16
Until: 16 March 2013 (afternoon)	Max. 19	Min. 15
Drainage rate	**cm^3/min**	
At the beginning of the wetting time	300	
At the middle of the wetting time	190	
At the end of the wetting time	80	

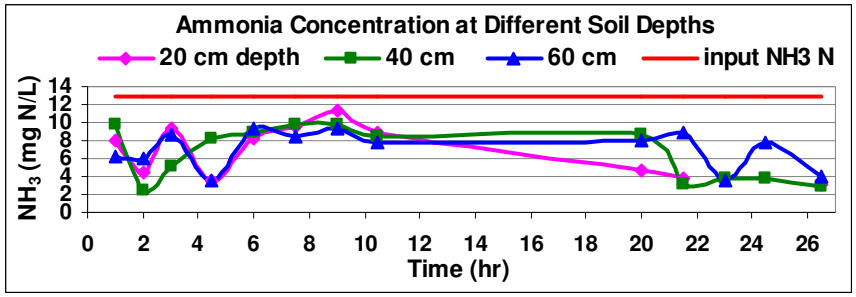

Figure 5.73: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle One – Third Run - First Wetting Drying Schedule).

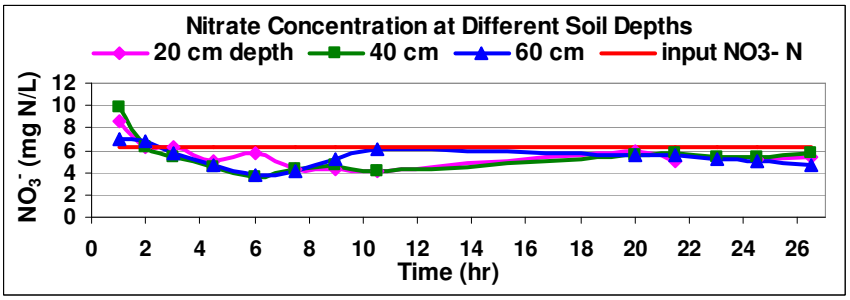

Figure 5.74: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle One – Third Run - First Wetting Drying Schedule).

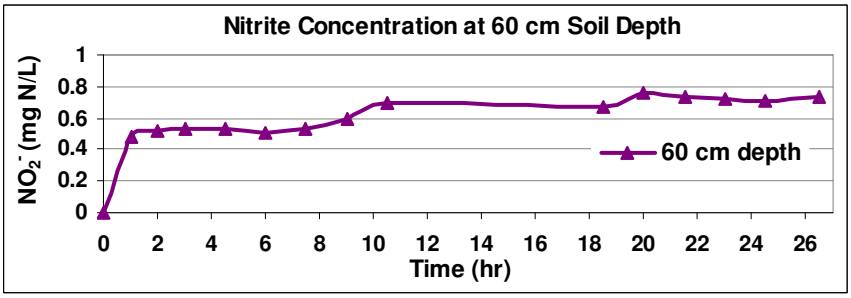

Figure 5.75: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle One – Third Run - First Wetting Drying Schedule).

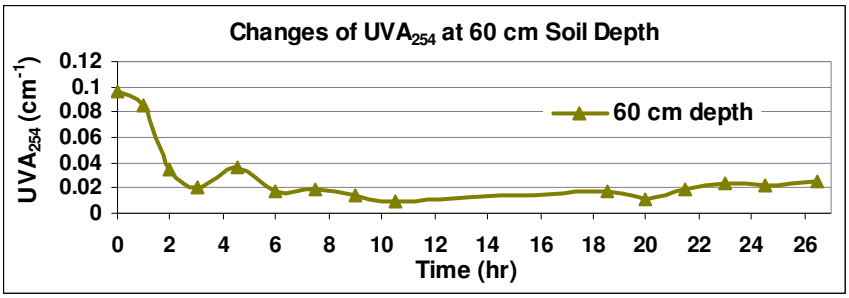

Figure 5.76: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle One – Third Run - First Wetting Drying Schedule).

5.5.1.11 Experiment No. 23:

Distribution of nitrogen species through SAT column during **cycle two of the third run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.25: Conditions of experiment No. 23:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 18 March 2013 (afternoon)	Max. 17 Min. 13
Until: 19 March 2013 (afternoon)	Max. 18 Min. 13
Drainage rate	**cm^3/min**
At the beginning of the wetting time	30
At the middle of the wetting time	25
At the end of the wetting time	20

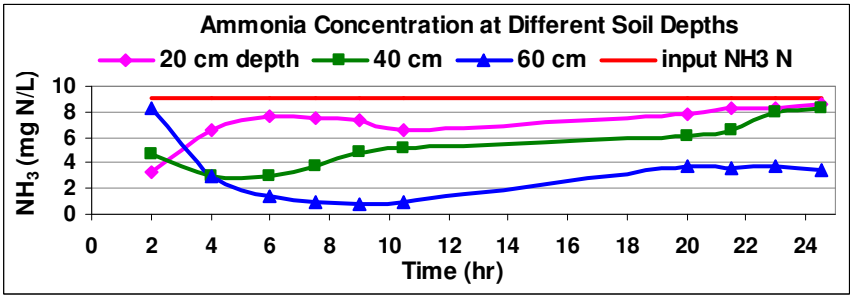

Figure 5.77: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – Third Run - First Wetting Drying Schedule).

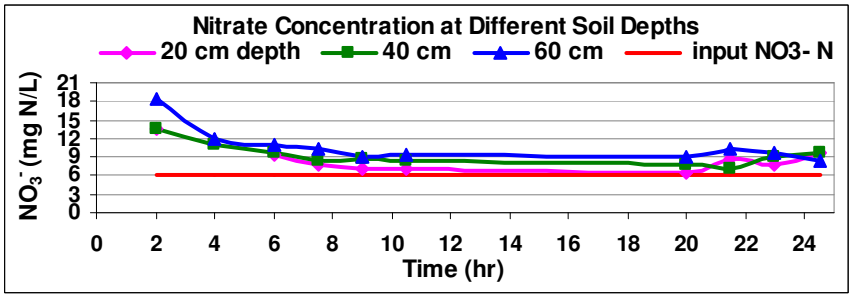

Figure 5.78: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – Third Run - First Wetting Drying Schedule).

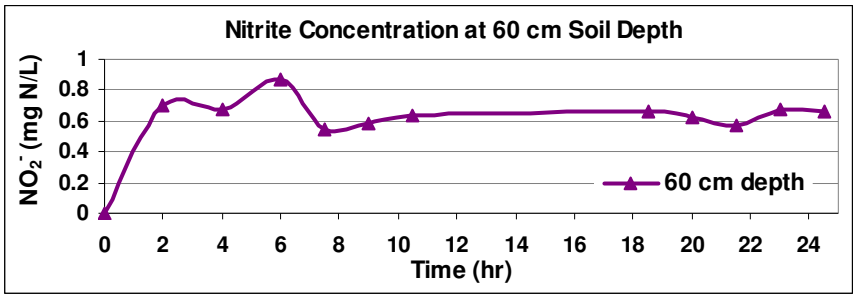

Figure 5.79: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Two – Third Run - First Wetting Drying Schedule).

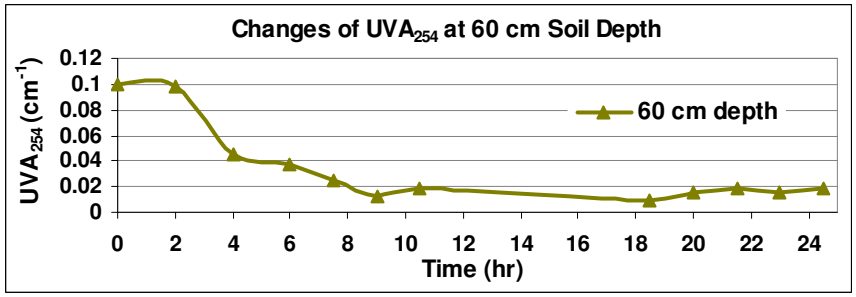

Figure 5.80: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Two – Third Run - First Wetting Drying Schedule).

5.5.1.12 Experiment No. 24:

Distribution of nitrogen species through SAT column during **cycle three of the third run** is by applying 24 hours wetting / 48 hours drying operating schedule.

Table 5.26: Conditions of experiment No. 24:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 21 March 2013 (afternoon)	Max. 22 Min. 15
Until: 22 March 2013 (afternoon)	Max. 29 Min. 16
Drainage rate	**cm^3/min**
At the beginning of the wetting time	60
At the middle of the wetting time	100
At the end of the wetting time	55

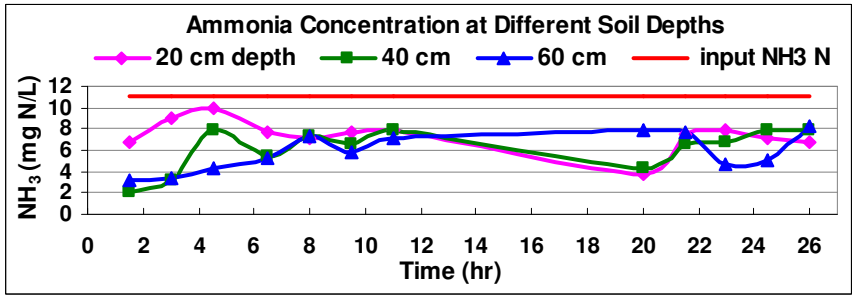

Figure 5.81: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – Third Run - First Wetting Drying Schedule).

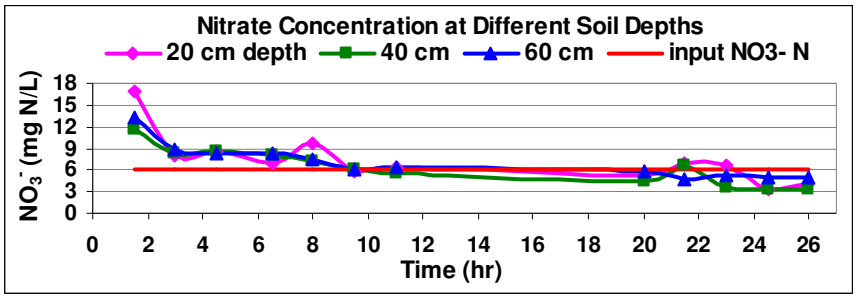

Figure 5.82: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – Third Run - First Wetting Drying Schedule).

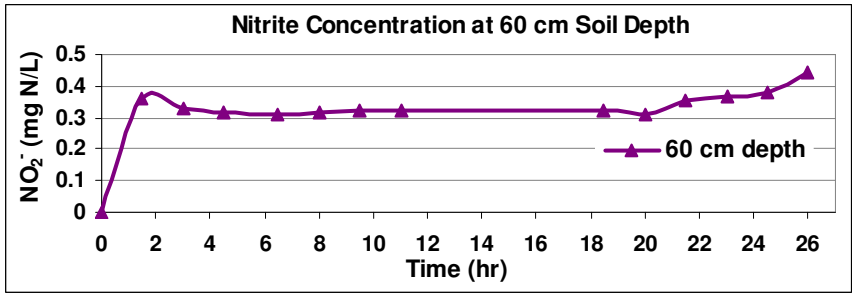

Figure 5.83: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Three – Third Run - First Wetting Drying Schedule).

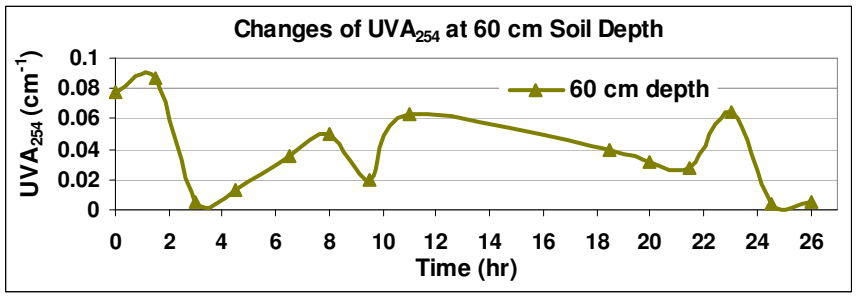

Figure 5.84: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Three – Third Run - First Wetting Drying Schedule).

5.5.2 RESULTS OF THE FIFTH SET OF EXPERIMENTS: EXPERIMENTS (No. 25 TO 30) USING SOIL (C) – SECOND WETTING DRYING SCHEDULE

5.5.2.1 Ammonia removal:

The overall efficiency of initial ammonia removal in this set of experiments was ranging from 20 % in cycle two of the second run (experiment No. 29) as shown in figure 5.101 to 44% in cycle two of the first run (experiment No. 26) as shown in figure 5.89. The average of overall ammonia removal efficiency was about 35%,

which is considered low as compared to the average of initial ammonia removal by applying the first operating schedule on the same soil (fourth set of experiments).

The low rate of nitrification in this set of experiments attributed mainly to the short drying time which was not enough to dry the soil effectively and reduced oxygen diffusion through the soil surface and so the nitrification performance was decreased, and to the low average of hydraulic retention time which was about 4.8 hr in addition

5.5.2.2 Nitrate removal:

Although seasonal temperature range was relatively high during this set of experiments, where it was between 15 and 30°C, but it was observed that the average of overall initial nitrates reduction efficiency in this set of experiments was relatively low and about 7% because of the short wetting time (12 hours) which was not enough to create anaerobic conditions in the soil column.

In cycle two of the first run (experiment No. 26), the average of drainage rate was about 80 ml/min as shown in table 5.28 and the hydraulic retention time was about 4.6 hr, and no significant removal of the initial nitrate was observed as shown in figure 5.90. But in cycle three of the second run (experiment No.30), the average of drainage rate was about 28 ml/min as presented in table 5.32 and the hydraulic retention time was about 13 hr, the overall reduction of the initial concentration of nitrate at the outlet of soil column (60 cm soil depth) was about 26% as shown in figure 5.106.

5.5.2.3 Nitrite removal:

The average of overall nitrite concentration at the end wetting times was bout 0.59 mg N/L during this set of experiments because of high drainage rates and short hydraulic retention times as mentioned above.

In cycle one of the first run (experiment No.25), the average of drainage rate was about 90 ml/min as presented in table 5.27 and the retention time was about 4 hr, nitrite concentration at the end of wetting time was about 1 mg N/L as shown in figure 5.87. While in cycle two of the second run (experiment No.29), the average of drainage rate was about 45 ml/min as presented in table 5.31 and the retention time was about 8.2 hr, nitrite concentration at the end of wetting time was about 0.27 mg N/L as shown in figure 5.103, which indicates that nitrite reduction increases with the increase of hydraulic retention time.

5.5.2.4 Reduction of initial UVA_{254} values:

In general, there was a high decreasing of initial UVA_{254} values during this set of experiments. In cycle one of the second run (experiment No.29), the ambient temperature was ranging between 16 and 21°C as presented in table 5.31 and the average of total reduction of initial UVA_{254} value was 75% as shown in figure 5.100. The average of overall reduction of initial UVA_{254} values during this of experiments was about 71% which implies high bacterial activity and high biodegradation of dissolved organic compounds because of the relatively high seasonal temperature.

The following figures show the distribution of ammonia concentration, percentage of ammonia removal, distribution of nitrate concentration, distribution of nitrite concentration and UVA_{254} values at different soil depths during the fourth set of experiments (experiments No. 25 to 30). Tables 5.27 to 5.32 illustrate the conditions of the experiments with respect to temperature degrees during the experiments, the drainage rates and the date of experiments.

5.5.2.5 Experiment No. 25:

Distribution of nitrogen species through SAT column during **cycle one of the first run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.27: Conditions of experiment No. 25:

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 29 March 2013 (afternoon)	Max. 24 Min. 17
Drainage rate	**cm^3/min**
At the beginning of the wetting time	80
At the middle of the wetting time	110
At the end of the wetting time	85

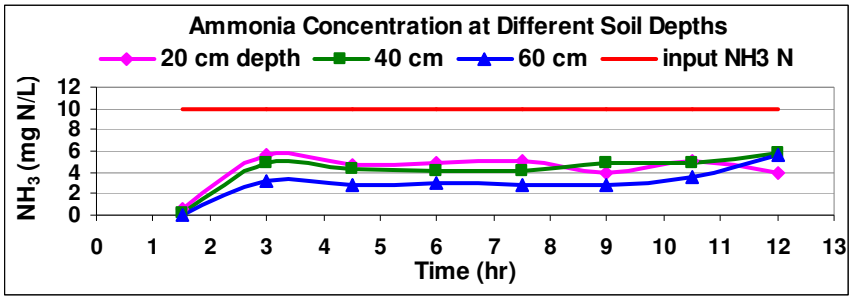

Figure 5.85: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle One – First Run - Second Wetting Drying Schedule).

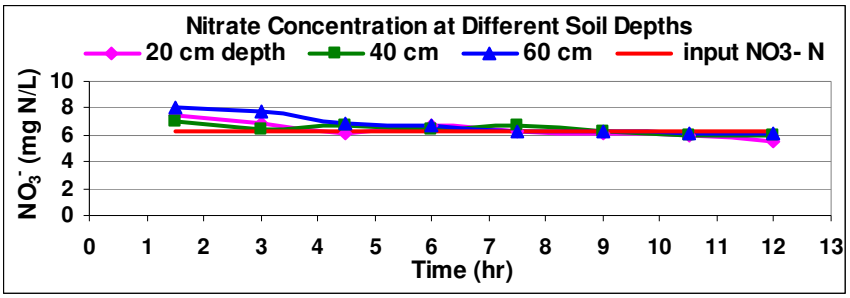

Figure 5.86: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle One – First Run - Second Wetting Drying Schedule).

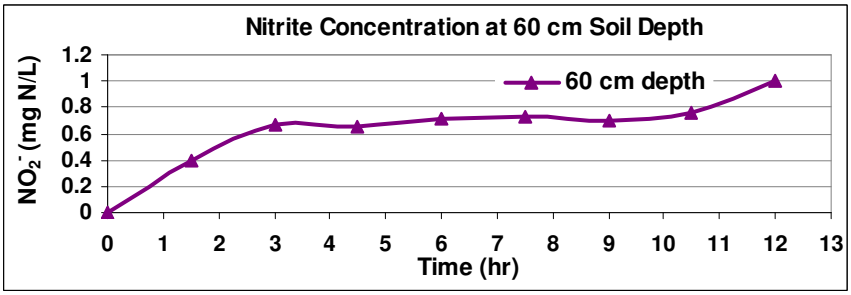

Figure 5.87: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle One – First Run - Second Wetting Drying Schedule).

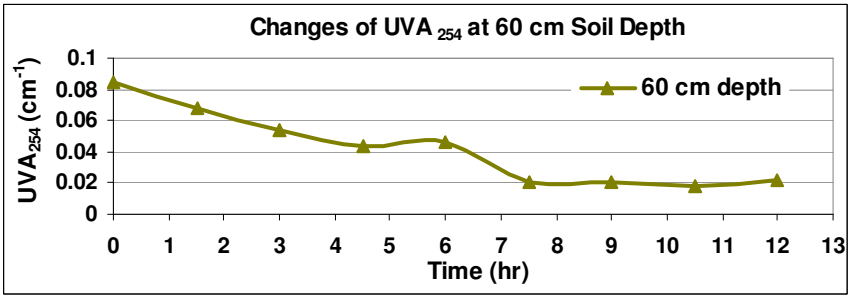

Figure 5.88: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle One – First Run - Second Wetting Drying Schedule).

5.5.2.6 Experiment No. 26:

Distribution of nitrogen species through SAT column during **cycle two of the first run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.28: Conditions of experiment No. 26**:**

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 30 March 2013 (afternoon)	Max. 30 Min. 20
Drainage rate	**cm^3/min**
At the beginning of the wetting time	80
At the middle of the wetting time	90
At the end of the wetting time	65

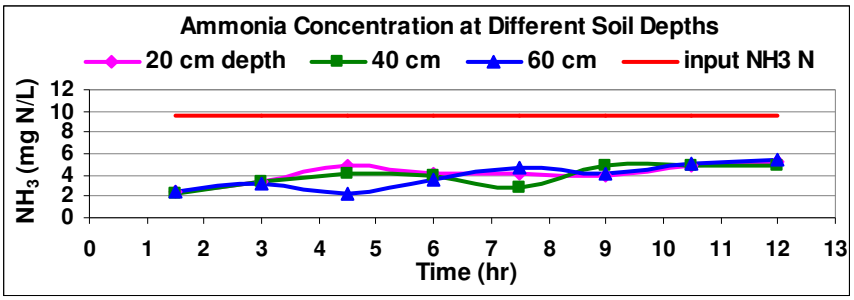

Figure 5.89: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – First Run - Second Wetting Drying Schedule).

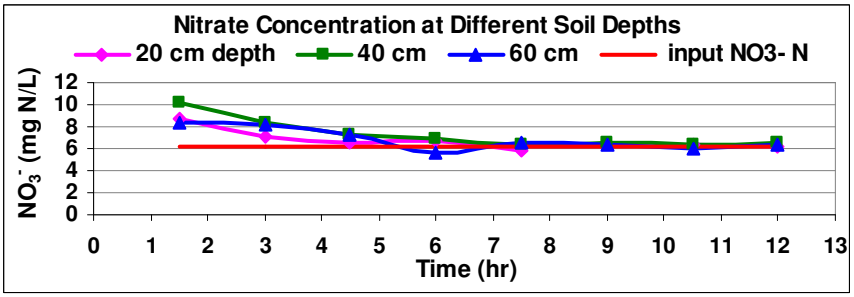

Figure 5.90: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – First Run - Second Wetting Drying Schedule).

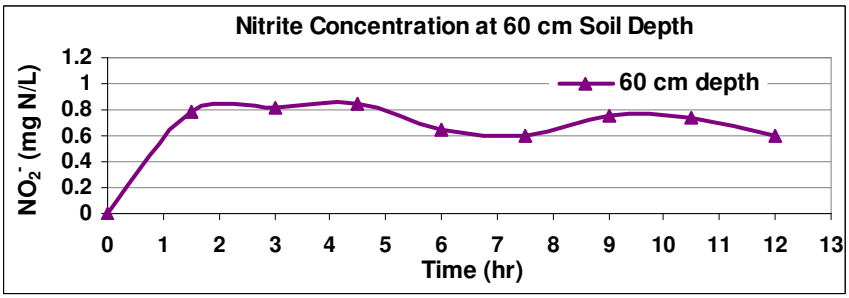

Figure 5.91: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Two – First Run - Second Wetting Drying Schedule).

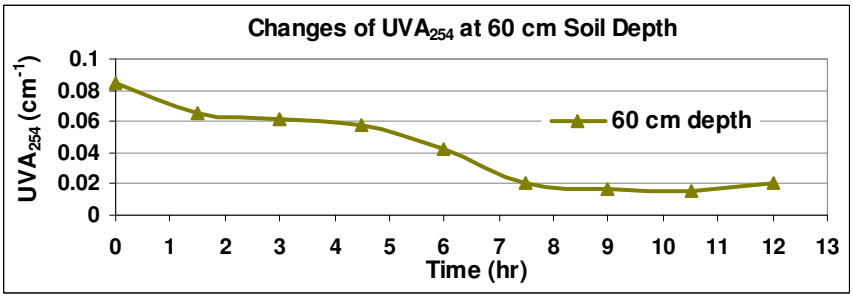

Figure 5.92: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Two – First Run - Second Wetting Drying Schedule).

5.5.2.7 Experiment No. 27:

Distribution of nitrogen species through SAT column during **cycle three of the first run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.29: Conditions of experiment No. 27:

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 31 March 2013 (afternoon)	Max. 28 Min. 19
Drainage rate	**cm^3/min**
At the beginning of the wetting time	80
At the middle of the wetting time	90
At the end of the wetting time	55

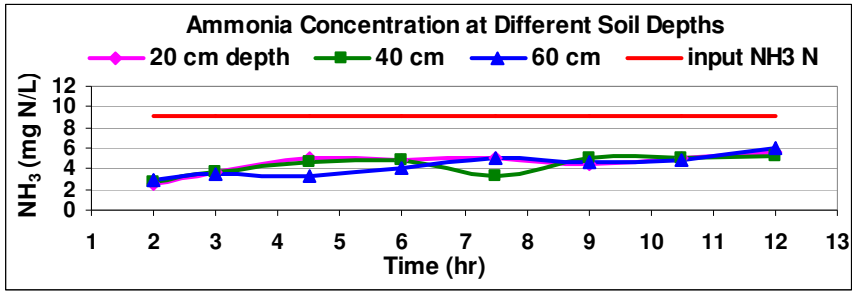

Figure 5.93: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – First Run - Second Wetting Drying Schedule).

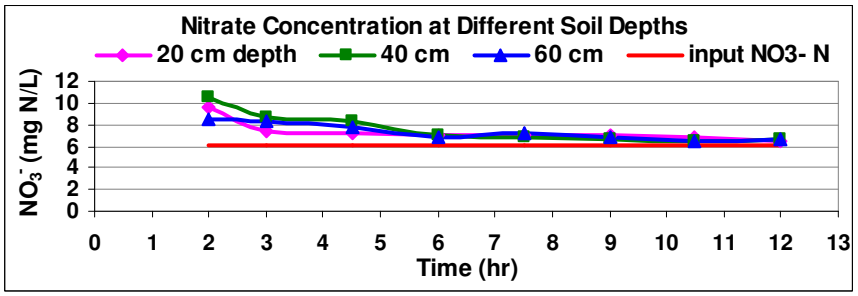

Figure 5.94: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – First Run - Second Wetting Drying Schedule).

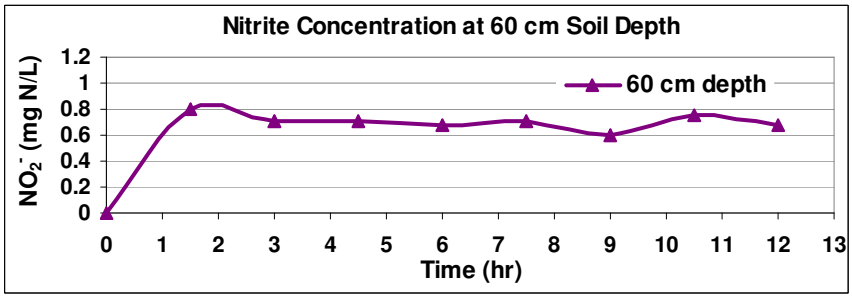

Figure 5.95: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Three – First Run - Second Wetting Drying Schedule).

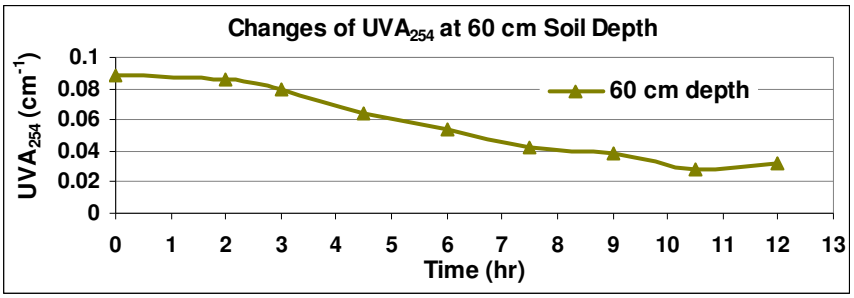

Figure 5.96: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Three – First Run - Second Schedule).

5.5.2.8 Experiment No. 28:

Distribution of nitrogen species through SAT column during **cycle one of the second run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.30: Conditions of experiment No. 28

Date of the experiment (wetting time)	Temperature Degree (°C)
Start: 4 April 2013 (afternoon)	Max. 21 Min. 16
Drainage rate	**cm^3/min**
At the beginning of the wetting time	90
At the middle of the wetting time	130
At the end of the wetting time	95

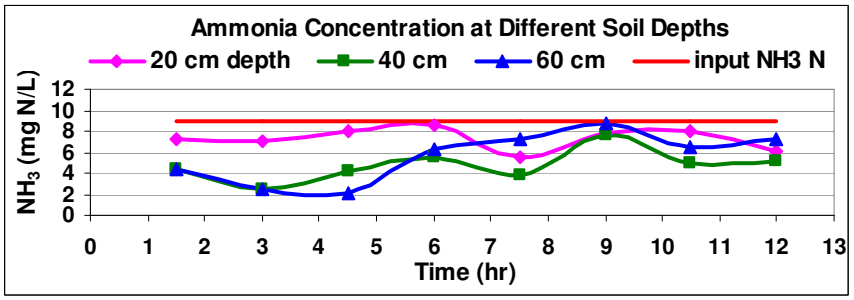

Figure 5.97: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle One – Second Run - Second Wetting Drying Schedule).

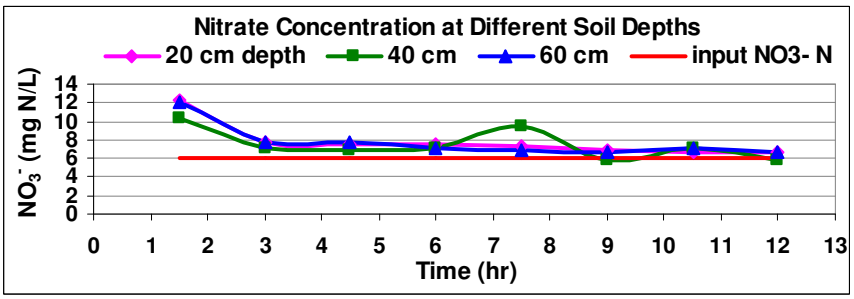

Figure 5.98: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle One – Second Run - Second Wetting Drying Schedule).

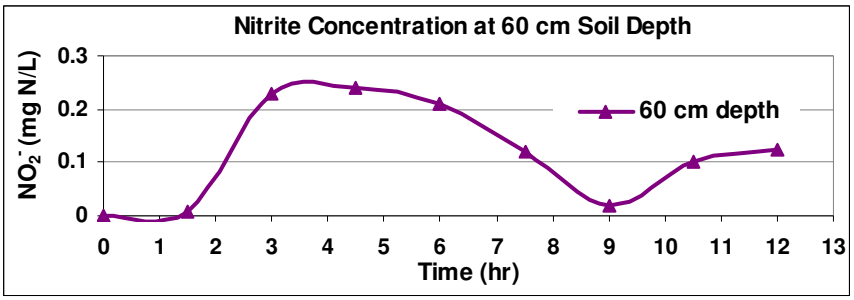

Figure 5.99: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle One – Second Run - Second Wetting Drying Schedule).

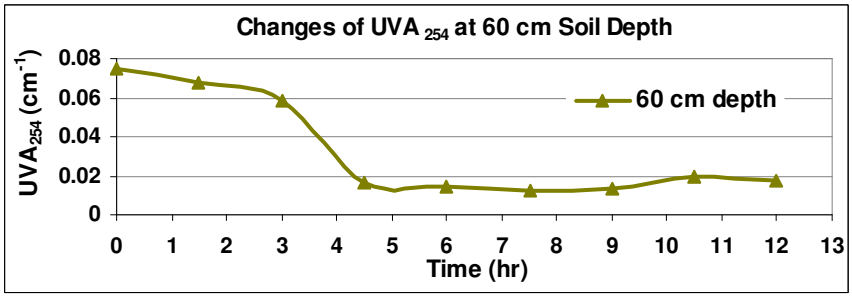

Figure 5.100: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle One – Second Run - Second Wetting Drying Schedule).

5.5.2.9 Experiment No. 29:

Distribution of nitrogen species through SAT column during **cycle two of the second run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.31: Conditions of experiment No. 29:

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 5 April 2013 (afternoon)	Max. 22 Min. 16
Drainage rate	**cm^3/min**
At the beginning of the wetting time	60
At the middle of the wetting time	50
At the end of the wetting time	35

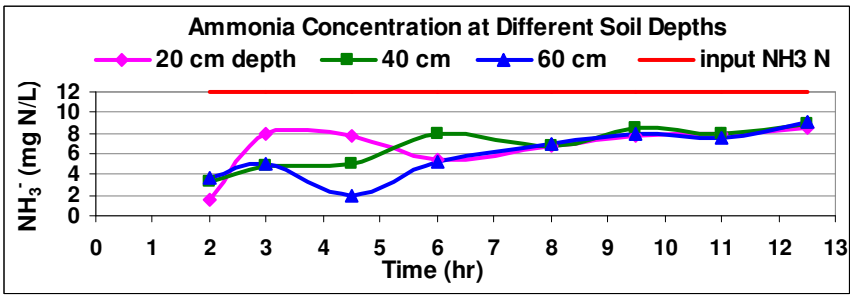

Figure 5.101: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – Second Run - Second Wetting Drying Schedule).

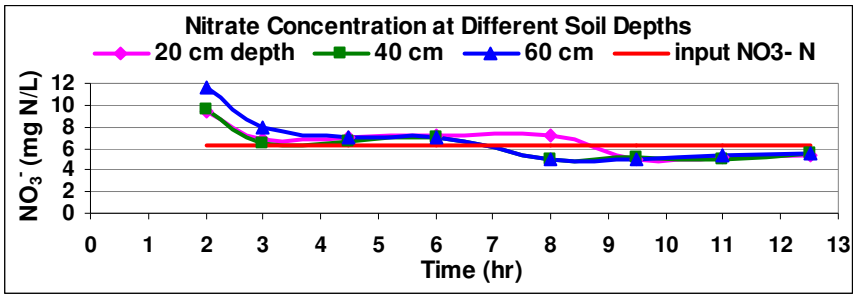

Figure 5.102: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Two – Second Run - Second Wetting Drying Schedule).

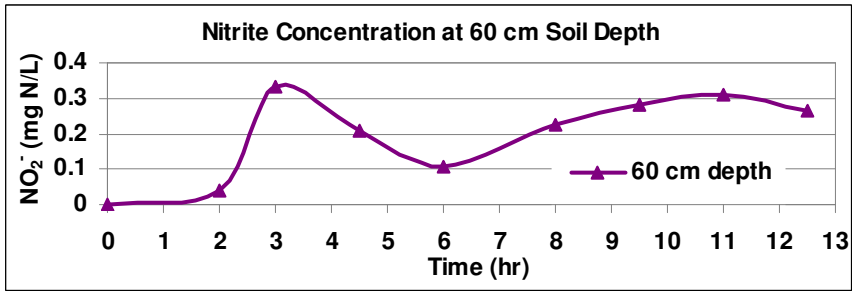

Figure 5.103: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Two – Second Run - Second Wetting Drying Schedule).

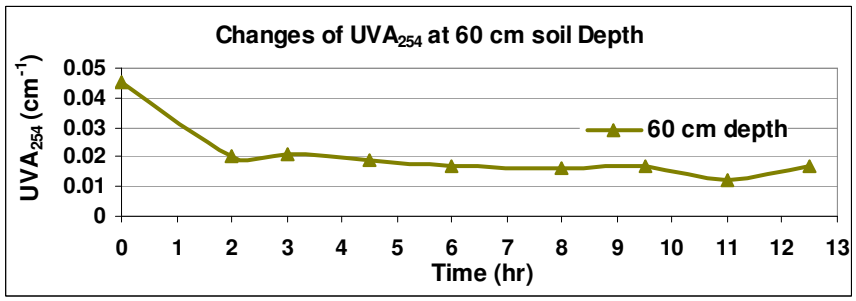

Figure 5.104: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Two – Second Run - Second Wetting Drying Schedule).

5.5.2.10 Experiment No. 30:

Distribution of nitrogen species through SAT column during **cycle three of the second run** is by applying 12 hours wetting / 12 hours drying operating schedule.

Table 5.32: Conditions of experiment No. 30

Date of the experiment (wetting time)	**Temperature Degree (°C)**
Start: 6 April 2013 (afternoon)	Max. 25 Min. 18
Drainage rate	**cm^3/min**
At the beginning of the wetting time	40
At the middle of the wetting time	30
At the end of the wetting time	17

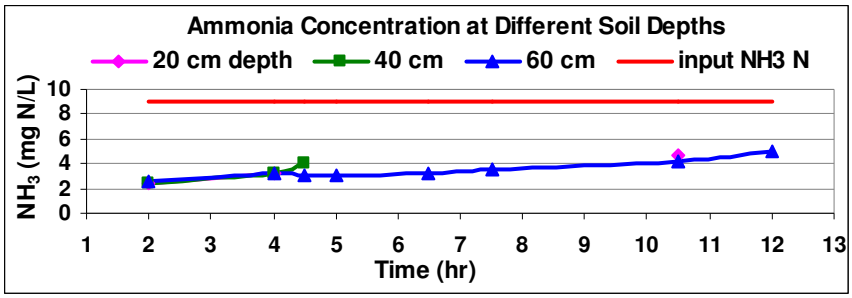

Figure 5.105: Distribution of Ammonia Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

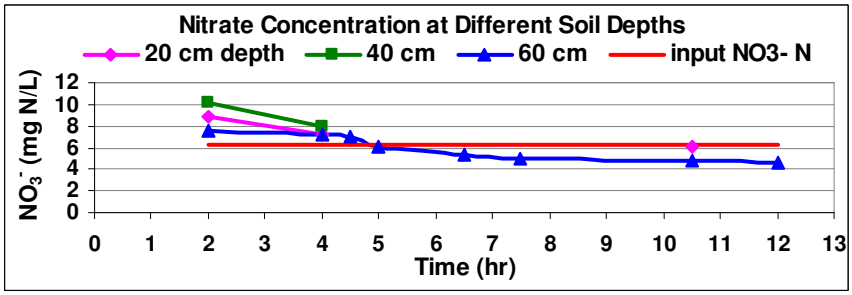

Figure 5.106: Distribution of Nitrate Concentration at Different Soil Depths Using Soil (C) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

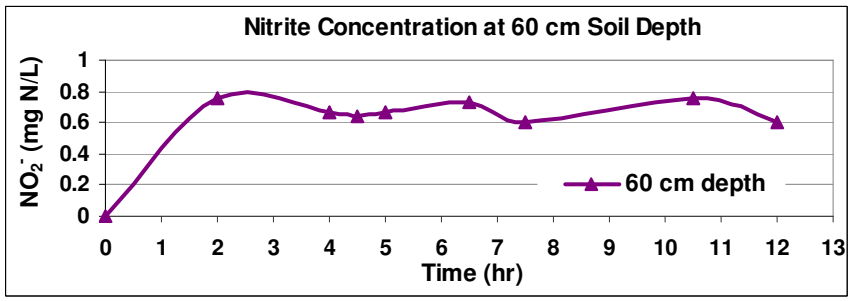

Figure 5.107: Distribution of Nitrite Concentration at 60 cm Soil Depth Using Soil (C) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

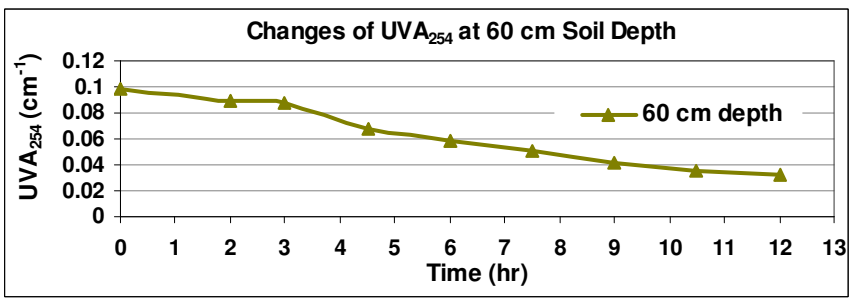

Figure 5.108: Changes of UVA_{254} as a function of time at 60 cm Soil Depth Using Soil (C) – (Cycle Three – Second Run - Second Wetting Drying Schedule).

CHAPTER SIX

GENERAL DISCUSSION

6.1 INTRODUCTION

The effect of wetting and drying times in addition to the influence of other factors on ammonia, nitrate and nitrite removal during this study will be discussed in this chapter. The general results of this study are concluded in table 6.1 which presents the average ammonia removal efficiency, average of nitrate removal efficiency, average of effluent nitrite concentration at the end of wetting times, overall reduction of UVA_{254} values, average of seasonal temperature degrees and average of hydraulic retention time.

Table 6.1: General results of the study

Soil type and wetting drying schedule	Average of ammonia removal efficiency	Average of nitrate removal efficiency	Average of nitrite at the end of wetting time (mg N/L)	Overall reduction of UVA_{254} values	Average of seasonal temperature degrees (°C)	Average of hydraulic retention time (hr)
Soil A – First wetting drying schedule	84%	56%	–	–	21	9
Soil B – First wetting drying schedule	60.5%	0%	0.59	31%	10	4.5
Soil B – Second wetting drying schedule	61%	2%	0.3	36%	14	9
Soil C – First wetting drying schedule	60.3%	15%	0.55	61%	20	3.4
Soil C – Second wetting drying schedule	35%	7%	0.59	71%	21	4.8

6.2 Effect of wetting and drying times on ammonia removal:

The results presented in table 6.1 indicate that when the first wetting drying schedule (24 hours wetting / 48 hours drying) was applied on soil C, the average of ammonia removal efficiency was higher than the second wetting drying schedule (12 hour wetting / 12 hours drying) when it applied on soil C, because the increase of wetting time in the first wetting drying schedule increased the depth at which ammonia is adsorbed, while the increase of the drying time dried the soil to some extent and increased the oxygen diffusion through the soil surface to greater depths which increased ammonia oxidation and improved the nitrification performance (Pescod, 1992).

Short drying time in the second wetting drying schedule was not enough to dry the soil effectively, and so oxygen diffusion through the soil surface reduced due to the influence of soil water content (Jellali et al., 2009). However, the average of initial ammonia removal efficiency by applying the first wetting drying schedule on soil C was 60.3%, while it was 35% when the second wetting drying schedule was applied on the same soil.

the average of ammonia removal efficiency was similar when the first wetting during schedules was applied on soil B and soil C, while the average of ammonia removal efficiency was improved when the second wetting drying schedule was applied on soil B as compared with soil C, because the average of hydraulic retention time (HRT) when the second wetting drying schedule was applied on soil B was about 9 hours as presented in table 6.1, which was higher than the HRT when the second wetting drying schedule was applied on soil C, and so resulted in an increase of ammonia removal and the nitrification performance (malolo, 2011).

The maximum efficiency of ammonia removal was observed when the first wetting drying schedule was applied on soil A, which was about 84% because soil A had higher cation exchange capacity (CEC) than soil B and soil C as presented in table 5.1, which increased the mechanism of ammonia adsorption and so improved the nitrification performance.

Because of the relatively high alkaline pH of soil A, B and C as presented in table 5.1, high removal of ammonia in some experiments could be also due to a

combination of volatilization and adsorption with subsequent nitrification (Crites et al., 2000).

6.3 Effect of wetting and drying times on nitrate removal:

Results in table 6.1 show that the average of nitrate removal increased when the first wetting drying schedule (24 hours wetting / 48 hours drying) was applied on soil C as compared with the second wetting drying schedule (12 hour wetting / 12 hours drying), because long wetting time in the first wetting drying schedule created anaerobic conditions which increased the denitrification performance and nitrate removal (Amy et al., 1993). The average of initial nitrate removal efficiency by applying the first wetting drying schedule on soil C was 15%, while it was 7% when the second wetting drying schedule was applied**.** The increase of denitrification rates with increasing the wetting and drying times was also consistence with other researcher's results such as Gungor and Unlu, (2004).

When the first and the second wetting drying schedules were applied on soil B at relatively at low seasonal temperature the average of nitrate removal efficiency was very low because the denitrification rates decreased under cold conditions due to the decrease of the growth rate and the activity of denitrifying bacteria (Onnis-Hayden and Gu, 2008).

The maximum nitrate removal efficiency was observed when the first wetting drying schedule was applied on soil A, which was 56% because soil A had higher percentage of clay and silt than soil B and soil C as presented in table 5.1, and so it had smaller soil pores than soil B and soil C, which resulted in higher prospect of anaerobic sites for denitrification processes (Sexstone et al., 1985). The average hydraulic retention time decreased to 9 hours when soil A was used in the soil column due to the high percentage of Clay and silt, which increased also the denitrification performance.

6.4 Effect of wetting and drying times on nitrite removal:

Nitrite concentration changes were observed during the wetting times due to nitrification and denitrification processes . As presented in table 6.1 when the first and second wetting drying schedules were applied on soil B and soil C, the average of effluent nitrite concentration at the end of wetting times was less than 0.6 mg N/L .

The average of nitrite removal was increased when the second wetting drying schedule was applied on soil B because the average of hydraulic retention time during this set of experiments was higher than the average of hydraulic retention time during the other sets of experiments using soil B and soil C as presented in table 6.1.

6.5 Reduction of initial UVA_{254} values:

As presented in table 6.1, when the first and the second wetting drying schedules were applied on soil C at a relatively high seasonal temperature which increased the activity and the growth rate of bacteria in the soil column (Fiorenza et al., 1991). And so, the average of overall reduction of initial UVA_{254} values increased to 61% and 73% by applying the first and the second wetting drying schedules applied on soil C respectively, due to the increase of organic matter biodegradation (Amy and Drewes, 2007).

While when the two wetting drying schedules were applied on soil B at a relatively low seasonal temperature, the average of overall reduction of initial UVA_{254} values decreased to 31% and 36% by applying the first and the second wetting drying schedules on soil B respectively, and also the denitrification performance reduced during this set of experiments due to the decrease of bacterial activity.

CHAPTER SEVEN

CONCLUSIONS & RECOMMENDATIONS

6.1 CONCLUSIONS:

The duration of this study extended from November 11, 2012 until April 6, 2013, the efficiency of SAT in removing nitrogen species from artificial wastewater were evaluated by comparing the quality of influent wastewater (before SAT) and the quality of effluent wastewater of the soil column (after SAT). The effects of different wetting drying schedules on ammonia, nitrate and nitrite compounds by using different types of soil are summarized in table 6.1. The results of this study indicated a good potential for nitrogen species removal from wastewater through SAT system under Gaza city conditions. The significant observations of this research were as follow:

1. When the first wetting drying schedule (24 hours wetting/48 hours drying) was applied on soil C, the efficiency of ammonia and nitrate removal was 60.3% and 15% respectively, while when the second wetting drying schedules (12 hours wetting/12 hours drying) was applied on soil C, the efficiency of ammonia and nitrate removal was 35% and 7% respectively, which implies that the first wetting drying schedule had more efficiency than the second wetting drying schedule to remove ammonia and nitrate.
2. When the first and the second wetting drying schedules were applied on the soil B at cold conditions the average of ammonia removal efficiency was 60.5% and 61% respectively, while the average of nitrate removal efficiency was insignificant.
3. When the first wetting drying schedule was applied on soil A (sandy loam soil), removal efficiency of ammonia and nitrate was the highest and about 84% and 56% respectively, because soil A had the highest cation exchange capacity (CEC) as compared to soil B and soil C
4. The average of the formed nitrite concentration at the end of wetting times was less than 0.6 mg N/L by applying the first and the second wetting drying schedules on soil B and soil C. But it was observed more reduction in the average

of nitrite concentration at the end of wetting times when the second wetting drying schedule was applied on soil B, which was about 0.3 mg N/L because the hydraulic retention time decreased in this set of experiments as compared to the other sets of experiments.

5. High reduction in UVA_{254} values was observed when high seasonal temperature was prevailed because of the increased bacterial activity. The average of overall reduction of initial UVA_{254} values was 61% and 71% when the first and the second wetting drying schedules were applied respectively on soil C in March and April where seasonal temperature was rather high. While the average of overall reduction of initial UVA_{254} values was 31% and 36% when the first and the second wetting drying schedules were applied respectively on soil B in January and February where seasonal temperature was rather low.
6. The average of drainage rates of soil A, soil B and soil C were 40, 83 and 109 ml/min respectively when the first operating schedule was applied, while it was 40 and 71 ml/min when the second operating schedule was applied on soil B and soil C respectively. Which implies that soil C, which is the soil of the existing infiltration basin in Gaza city wastewater treatment plant, had the highest hydraulic loading rate as compared to soil A and soil B.

6.2 RECOMMENDATIONS:

According to the finding of this study, the following recommendations are made:

1. Further studies are required to analyze the effect of wetting and drying time on removal of nitrogen species by application of different and longer operating schedules, conducting column and batch experiments, in addition to pilot-scale studies in the field.
2. Studies on the effect of different wetting drying schedules should be done at same time to avoid the effects of seasonal temperature variations.
3. Studies about removal of multiple contaminants other than nitrogen forms during SAT system by application of secondary treated wastewater are recommended.
4. Studies about the effect of using different types of soil in SAT system are recommended.
5. It is recommended to reduce pumping rate of wastewater to the infiltration basin in winter months such as January and February where seasonal temperature degrees are low and the efficiency of contaminants removal reduced.

6. Further field studies about the effect of seasonal temperature variations on the removal of different contaminants by SAT system are needed.
7. Application of SAT system with a good management and follow up actions to prevent groundwater pollution is recommended as apart of solving the problem of domestic water shortages and surplus amount of wastewater production.

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