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MODELING SOLUTE TRANSPORT FOR IMPROVED FERTILISER USE IN RICE PRODUCTION SYSTEM

ABDIKANI ABDULLAHI MO'ALLIM

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By

ABDIKANI ABDULLAHI MO'ALLIM

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

June 2018

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DEDICATION

This thesis is dedicated to;

My parents for their endless love and wishes for their son to achieve this higher dream,

My two elder sisters, Naima and Hamdi Abdullahi, who has been supportive during my study,

My sibilings, Decca, Abdikarim, and Abdiaziz Abdullahi, who have been a source of inspiration to me throughout my study.

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

MODELING SOLUTE TRANSPORT FOR IMPROVED FERTILISER USE IN RICE PRODUCTION SYSTEM

By

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June 2018

Chairman : Md Rowshon Kamal, PhD
Faculty : Engineering

Quantification of water and nutrients and their interactions of a paddy field environment are crucial for the improved utilization of fertilizers for the sustainable rice production. Solutes runoff and leaching are two direct pathways of nutrient pollution from paddy fields to water resources systems. Due to the dynamic nature of paddy fields, solute transport and transformation process are complex and difficult to understand. The past investigation on the water balance components using multifarious parameters did not reflect the true condition of paddy field environments. Quantification of agrochemical losses from paddy fields are generally related to the amount of inflow and outflow water in the paddy field environment which yet to be measured accurately. In order to overcome the challenges, the modern monitoring devices together with sensors and data logging system were installed for intensive field observations in a paddy and developed empirical models to quantify the solute losses through the surface and sub-surface water leaving from a paddy field system for the better utilization of fertilizers (N, P, K). The intensive field investigation was carried out in a paddy plot at Sawah Sempadan compartment of the Tanjung Karang Rice Irrigation Scheme (TAKRIS) for two rice growing seasons (January-April and July-October) in 2017.

Firstly, the water balance components in a paddy plot was analysed from the intensive field observations with 1-10 minutes interval of a paddy field. Water balance analysis results revealed that irrigation water accounted 59.6 % of the total water input (irrigation and rainfall) during the January to April (Off Season). However, about 76.2% of total water input during the July to October (Main season). The amount of rainfall contributed to 23.8% and 40.4% of total water input in the main season and off-season, respectively. Drainage flow accounted 37.3% and 43.7% of the total water input during off season and main season, respectively. The

daily evapotranspiration accounted 41.7% and 61% of total water input during off-season and main season, respectively. Observed seepage and percolation of 17.1% to 19.2% of total water input accounted during both seasons respectively. The yield of the experimental plot was obtained 2.5 t/ha and 2.7 t/ha for the off season and main season, respectively. Finally, the water productivity index was analyzed 0.72 kg m^{-3} during off-season and 0.78 kg m^{-3} during main season, respectively.

Based on solute transport analysis, the accumulated total nitrogen (T-N) of 50.3% to 49.7% estimated in the top 40 cm soil layer while 49.7 % to 53 % T-N as leachate obtained below 40 cm soil layer (40-100 cm) during off season and main season, respectively. About 85% of N leaching losses were in the form of $NO3^-$, however there was still a large quantity of $NO3^-$ remained below root zone that contributes the groundwater. The total leaching loss of T-N was 34.9 and 27.9 kg/ha during off and main seasons respectively. The estimated loss of total phosphorous during the two rice growing seasons were 3 and 1.7 kg/ha, respectively. The total amount of T-N, T-P and K loss through drainage were 27.7 and 18.5, 2.2 and 1.1, 5.9 and 3.5 kg/ha during off-season and main season, respectively.

The Hydrus-1D was applied to simulate water and solute movement under different soil depths of 20, 40, 60, 80 and 100 cm in real paddy environment experiments. The simulated and observed water flow and nutrient leaching were in good agreement (R^2= 0.98, RMSE = 0.24). Hydrus-1D simulation showed the similar patterns of the water and solute movement under different soil depths during the study period. The observed and simulated N, P and K concentration in paddy was high due to fertilization and other climatic factors. Therefore, reduction of excessive fertilizer rate especially during early rice growing period and adaptation of water saving techniques can reduce the pollutant risks from paddy soil.

Regression analyses were performed for the development of the improved fertilizer use models. Multiple linear regression analysis was performed to know the relationships between EC versus solutes (N, P and K) during the both seasons. The polynomial regression analysis was fitted to evaluate whether EC changes has an impact on N, P and K concentrations in paddy field. Finally, empirical models were established to estimate the concentrations of N, P and K using two rice growing season data. MS Excel solver program were used to develop the empirical models. The results obtained a strong agreement between observed and predicted N, P, and K with the determination coefficients (R^2) of 0.91 and 0.95 during the both seasons. Therefore, the models could be useful in predicting the solute concentration changes within root zone and below root zone during entire rice growing season for better utilization of fertilizers.

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

PERMODELAN PENGANGKUTAN BAHAN LARUT BAGI PENGGUNAAN BAJA YANG LEBIH BAIK DALAM SISTEM PENGELUARAN BERAS

Oleh

ABDIKANI ABDULLAHI MO'ALLIM

Jun 2018

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Kuantifikasi air dan nutrien serta interaksi mereka di dalam persekitaran padi adalah penting untuk penggunaan baja yang lebih baik bagi pengeluaran beras yang berkekalan. Bahan larut larian dan pengusaran adalah dua laluan langsung pencemaran nutrien dari sawah padi kepada sistem sumber air. Oleh kerana sifat padi yang dinamik, proses pengangkutan dan transformasi bahan larut menjadi kompleks dan sukar difahami. Penyiasatan lepas berkenaan komponen-komponen keseimbangan air menggunakan parameter yang pelbagai tidak mencerminkan keadaan sebenar persekitaran sawah padi. Kuantifikasi kerugian agrokimia dari sawah secara umumnya berkait dengan jumlah aliran masuk dan keluar air dalam persekitaran sawah padi yang belum diukur dengan tepat. Untuk mengatasi cabaran-cabaran ini, alat pemantauan moden bersama-sama dengan sensor dan sistem pengelogan data dipasang untuk pemerhatian lapangan yang intensif di dalam padi dan model empirikal yang dibangunkan bagi mengira kerugian bahan larut melalui permukaan dan sub-permukaan air yang meninggalkan sistem sawah padi untuk penggunaan baja yang lebih baik (N, P, K). Penyiasatan lapangan intensif dilakukan di plot padi di kompartmen Sawah Sempadan, Skim Pengairan Padi Tanjung Karang (TAKRIS) untuk dua musim penanaman padi (Januari-April dan Julai-Oktober) pada tahun 2017.

Pertama, komponen-komponen keseimbangan air dalam plot padi dianalisis dari pemerhatian lapangan intensif dengan jarak masa 1-10 minit pada sawah padi. Hasil analisa keseimbangan air menunjukkan bahawa air pengairan menyumbang 59.6% daripada jumlah input air (pengairan dan hujan) dari Januari hingga April (luar musim). Walau bagaimanapun, kira-kira 76.2% daripada jumlah input air diperhatikan dari bulan Julai hingga Oktober (musim utama). Jumlah air hujan menyumbang kepada 23.8% dan 40.4% daripada jumlah input air pada musim utama

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dan luar musim. Manakala air saliran menyumbang 37.3% dan 43.7% daripada jumlah input air semasa luar musim dan musim utama. Evapotranspirasi harian menyumbang 41.7% dan 61% daripada jumlah input air pada luar musim dan musim utama. Rembesan dan perkolasi sebanyak 17.1% kepada 19.2% diperhatikan daripada jumlah input air yang diambil kira dalam kedua-dua musim. Hasil dari plot eksperimentasi menunjukkan 2.5 t / ha dan 2.7 t / ha bagi luar musim dan musim utama. Akhirnya, indeks produktiviti air dianalisis sebanyak 0.72 kg m-3 semasa luar musim dan 0.78 kgm-3 semasa musim utama.

Berdasarkan analisis pengangkutan bahan larut, jumlah nitrogen (TN) yang terkumpul sebanyak 50.3% hingga 49.7% dianggarkan dalam lapisan tanah sedalam 40 cm manakala 49.7% hingga 53% TN bahan larut lesap diperoleh di bawah lapisan tanah sedalam 40 cm (40-100 cm) semasa luar musim dan musim utama. Kira-kira 85% daripada kehilangan pengurasan N adalah dalam bentuk $NO3^-$; namun, masih ada sejumlah besar $NO3^-$ yang kekal di bawah zon akar yang menyumbang air bawah tanah. Jumlah kehilangan pengurasan T-N adalah 34.9 dan 27.9 kg / ha masing-masing pada luar musim dan musim utama. Anggaran kehilangan jumlah fosforus selama dua musim penanaman padi masing-masing adalah 3 dan 1.7 kg / ha. Jumlah kerugian T-N, T-P dan K melalui saliran ialah 27.7 dan 18.5, 2.2 dan 1.1, 5.9 dan 3.5 kg / ha semasa luar musim dan musim utama.

Hidrus-1D digunakan untuk mensimulasikan pergerakan air dan bahan larut di bawah kedalaman tanah yang berbeza dari 20, 40, 60, 80 dan 100 cm dalam eksperimen persekitaran padi sebenar. Aliran air yang disimulasi dan diperhatikan dan pengusaran nutrien adalah sepadan (R2 = 0.98, RMSE = 0.24). Simulasi Hydrus-1D menunjukkan corak pergerakan air dan bahan larut yang sama di bawah kedalaman tanah yang berbeza semasa tempoh kajian. Kepekatan N, P dan K yang diperhatikan dan disimulasikan dalam padi adalah tinggi disebabkan faktor persenyawaan dan iklim lain. Oleh itu, pengurangan kadar baja yang berlebihan terutamanya semasa tempoh awal penanaman padi dan penyesuaian teknik penjimatan air dapat mengurangkan risiko pencemaran sawah padi.

Analisis regresi dilakukan bagi pembangunan model penggunaan baja yang lebih baik. Analisis regresi linier berganda dilakukan untuk mengetahui hubungan antara EC dan bahan larut (N, P dan K) semasa kedua-dua musim. Analisis regresi polinomial dipasang untuk menilai sama ada atau tidak perubahan EC mempunyai kesan terhadap kepekatan N, P dan K dalam sawah padi. Akhirnya, model empirikal ditubuhkan bagi menganggar kepekatan N, P dan K menggunakan dua data musim penanaman padi. Program penyelesaian MS Excel digunakan untuk membangunkan model empirikal. Hasil kajian memperoleh persefahaman yang kuat antara N, P, dan K yang diperhatikan dan yang dianggarkan dengan koefisien penentuan (R^2) 0.91 dan 0.95 semasa kedua-dua musim. Oleh itu, model-model ini boleh dikatakan berguna dalam meramal perubahan konsentrasi bahan larut dalam zon akar dan di bawah zon akar sepanjang musim penanaman padi untuk penggunaan baja yang lebih baik.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

MOA	Ministry of Agriculture
IPCC	Intergovernmental Panel on Climate Change
DOE	Department of Environment
SSL	self-sufficiency level
FAO	Food and Agriculture Organization
ICID	International Commission of Irrigation and Drainage
IRRI	International Rice Research Institute
ET	Evapotranspiration
ETo	Reference Evapotranspiration
RF	Rainfall
DR	Drainage
WL	Water Level
IR	Irrigation
Kc	Crop Coefficient
Mg/L	Milligram per litter
Kg/ha	Kilogram per hectare
mm	Millimetre
cm	centimetre
mm day^{-1}	Millimetre per day
cm day^{-1}	Cent meter per day

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LIST OF SYMBOLS

ρ	Density
Δ	slope of the saturation vapour pressure temperature relationship
γ	psychrometric constant
α	albedo or canopy reflection coefficient
ω	sunset hour angle
ϕ	latitude
δ	solar declination
σ	Stefan-Boltzman constant
$e^o (T_{min})$	saturation vapour pressure at daily minimum temperature
$e^o (T_{max})$	saturation vapour pressure at daily maximum temperature
Δt	length of time interval
Δz	effective soil depth

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

Rice is the main food crop in Malaysia. Rice production of the country has achieved 72% self-sufficiency level (SSL) with an annual production of 3.5 million tonnes a year (MOA, 2017). The Agriculture and Agro-based Industry Ministry targets the country to achieve a 100 percent self-sufficiency level (SSL) in paddy production by 2020. Irrigation is crucial to the world's food grain production because 40% of all crops and close to 60% of cereal production comes from irrigated agriculture (Phogat et al. 2010), even though irrigated lands comprise only 20% of the arable land (FAO, 2004). In Asia, irrigated agriculture uses 90% of the total freshwater, and more than half of this irrigates rice. About 75% of the global rice volume is produced in the irrigated low lands (Cantrell 2004). There are an estimated 150 million hectares of rice lands worldwide, 50% of which are irrigated, usually with continuous flooding for most of the crop season (Ghosh and Bhat 1998). In many irrigated areas, rice is grown as a monoculture with two rice crops every year. Global water and food security are one of the most important challenges in the 21st century to supply sufficient food for the increasing population while sustaining the stressed environment threatened by climate change. One of the main causes of land degradation is intensifying chemical fertilizer and pesticide usage (Bagheri et al. 2008; Bala et al. 2014 and Jean et al. 2015). In addition, a policy implemented by the government in term of subsidies is one of the encouragement factors for paddy farmers to adopt chemical substance in paddy cultivation techniques.

Rice production is one of the major non-point sources of fertilizers and pesticide pollution in Malaysia. Monitoring of these fertilizers and pesticide concentrations in river systems detected a number of chemicals commonly used in paddy fields, and these concentrations may appear to have adverse effects on the aquatic ecosystem. Most of the paddy fields are treated with fertilizers, herbicides, fungicides and insecticides which are applied during the crop season accordingly. Therefore, rice production is one of the major nonpoint sources of pollution. The typical paddy field in Malaysia is susceptible to fertilizers, pesticides and herbicides runoff since the chemicals are applied directly onto paddy water. Due to excessive use of chemicals in rice production in Malaysia compared to other Asian countries, it may presume that a significant amount of runoff along with fertilizers losses is occurring from paddy fields. Pesticides runoff losses from paddy fields range from a few percent to more than 50% of the applied amount depending on the water management (Maru, 1991 and Sudo et al., 2002). Inao et. al. (2008) highlighted that it is important to develop and validate mathematical models adapted to paddies in the Asian region in order to establish a realistic assessment and management procedure for environmentally-friendly rice production. Therefore, water quantity and distribution

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during the growing season is one of the key factors controlling crop growth and nutrients uptake in rice production.

There is increasing pressure on primary producers to reduce the environmental impacts of agricultural production. However, agricultural crop production systems are inherently sprinkling with respect to nutrients. Therefore, the challenge to producers is to manage their crop production systems in order to minimize environmental losses of nutrients, while achieving crop yield and quality targets. Many strategies have been developed in recent years to meet this challenge (Zebarth et al., 2009). These include: development of new tools to measure crop N status in order to refine in-season fertilizer N management, development of new soil N tests to improve prediction of soil N supply, development of new fertilizer N products with release patterns more closely matched to crop N uptake patterns, and development of site-specific N management strategies. A number of studies highlighted that water contaminated by nitrate is not potable and at high concentrations can be a serious risk for human health (Al-Redhaiman 2000; Anjana and Iqbal, 2007). Moreover, the water industry must bear additional costs to remove nitrates from groundwater sources (Harris et al. 1992; Cameron and Schipper 2010). The detrimental impacts of nitrate loss from the soil have toxicological implications for animals and humans (Camargo and Alonso, 2006), and also on the environment leading to the eutrophication of freshwater (London, 2005), and marine ecosystems (Beman et al. 2005). In rice production, the mineral commercial fertilizers anhydrous ammonia, urea, ammonium sulfate and ammonium nitrate are commonly applied. They are particularly soluble for easy assimilation by crops. Both urea and ammonia are converted to nitrate at different rates depending on the nature of the soil and of the climatic conditions, thus leading to various loss mechanisms either by volatilization for ammonia or runoff for nitrate or urea after heavy rainfall and leaching into groundwater (Vitosh et al. 1995; Jarvis et al. 2011). The most effective ways of improving the efficiency of fertilizers (N, P and K) use in agricultural crop production is the matching the supply of fertilizers to the crop demand in both space and time. This can be achieved by supplementing the supply of fertilizers from the soil with the appropriate rate and form of fertilizers, at the right time, and at the right location. While the concept is simple, this is difficult to achieve in practice due to substantial variation in both crop demand and in soil supply of fertilizers across years and among and within fields.

The increase in rice production can be achieved by efficient and good agricultural management practices, water and nutrient inputs. However, the use of conventional practice with poor management of plant nutrients and excessive fertilizer application will have a major impact in efforts to increase rice production in Malaysia. The importance of fertilizers for achieving increase crop production must be emphasized. Many rice varieties, particularly the high-yielding improved varieties currently being introduced into many traditional farming systems throughout the world, respond markedly to fertilization. When used in conjunction with good management practices (thorough land preparation, controlled irrigation, timely weeding) fertilizers can increase yields many times over. On the other hand, if used improperly fertilizers can

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damage crops, waste money, or possibly lead to a dependence on scarce chemical inputs.

Fertilizers are usually applied in Malaysia by conventional means. In paddy fields, the applied fertilizers, after dissolution, not only transport over and infiltrate into the soil, but also diffuse out and channel in all possible directions due to the transverse variation of water velocity and depth (Strelkoff et al. 2003). Deterioration of water quality in streams and lakes continues to be a significant issue in many counties (ICID, 2013). Causative factors include not only pollutants from various point sources but also those from non-point sources. The intensive use of agrochemicals for rice cultivation has been responsible for making paddy fields as a significant contributor of non-point source pollution. One of the most important factors contributing to this problem is the large amount of nutrients from non-point sources, especially agricultural paddy fields in which excessive chemical fertilizer application increases the concentration chemical loads (e.g. Nitrate nitrogen) in groundwater, which in turn results in the eutrophication of public water areas (Feng et al. 2004). Our understanding of nutrients/fertilizers transformation in paddy fields is limited due to complex interactions between soil, water, and biomass (Nakasone et al. 2004) and it is behavior in relation to plant growth in paddy soils has been extensively studied (De Datta, 1986). Therefore, forecasting hydrological pathways and pollutants (nutrient and pesticides) behavior in paddy soil appear to be crucial in order to define the specific management practices controlling non-point source pollution and preserving water resources (Tournebize et al. 2006).

Water management is a difficult task for a large rice irrigation system. Different sub-systems, such as soil, water, climate, nutrients, plant, management systems and their complex dynamics work in the paddy field environment. Furthermore, an individual irrigation scheme has its physical and unique characteristics. The effects of climate change are significant on water demand for irrigation that is continuously being aggravated by unsustainable practices like over-use of chemical fertilizers and poor water management. Excessive irrigation deliveries generate a huge amount of return flows containing fertilizers, insecticides, and pesticides from paddy fields in Malaysia. Eventually, drainage water from paddy fields loses the essential agrochemicals and pollutes the surface water resources. Poor and uneven water distributions were often criticized as the major bottleneck in attaining efficient water use in rice irrigation systems in Malaysia (JICA and DID, 1998; Rowshon et al. 2009). Ramli et al. (2012) reported that the removal of fertilizers' subsidy reduced rice production and the self-sufficient level (SSL) in Malaysia and overuse of agrochemicals results in serve environmental problems. Therefore, optimum application of fertilizers is crucial to minimize their loss and reduce environmental pollution. In this regard, reuse of drainage water has a potential to play a vital role in profitable rice production.

Many endeavors have been made to define nutrient rates as ideas of economic advantages, including mass-balance (Scarf et al. 2006), economically ideal fertilizer rate (Neeteson and Wadman, 1987; Sawyer et al. 2006), maximum return to N

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(Sawyer et al. 206) and information based ideal N compost (Zhu and Chen, 2002). Regardless, the vast majority of these suggestions addresses just site-specific ideal N rate. Such measures would be hard to reach out to a vast zone having distinctive rice assortments, environments, and cropping strategies. In addition, less consideration has been given as the measure of naturally ideal N rates. Our utilization of N manure has ended up far-reaching, bringing about serve natural issues (Chen et al. 2011). Hafeez et al. (2007) reported that rice production remained profitable despite high pumping costs to extract water from shallow tube wells for supplementary irrigation during dry seasons. In addition, small irrigation pumps owned by farmers can play an important role in capturing excess water that is drained from paddy fields to be reused in irrigation.

Excessive water and fertilizer inputs have led to a series of environmental problems in agricultural production areas around the world. Identifying the fates of water and nutrients is crucial to develop best management strategies in intensive agricultural production systems (Liang et al. 2018). Leon and Kohyama (2017) suggested that controlling and predicting nutrient losses into subsurface and surface water is vital for evaluating the environmental impacts of rice cultivation. Nutrient loss mechanism is complicated and shows remarkably regional differences due to spatial heterogeneities of underlying surface conditions, climate and agricultural practices (Zhang et al. 2016a). The regional heterogeneities of climate, underlying surface conditions and agricultural management practices also result in the remarkable regional differences of nutrient losses. A large number of applications also existed in the studies of hydrology and environmental observations or simulations, such as univariate analyses of extreme events and dam regulations (Zhang et al. 2016b).

Quantification of the amount of water used is very crucial for understanding and finding water use efficiency to an irrigation system level. Irrigation return flow consists of surface and subsurface flows. Water balance models, considering both components, can predict the return flow for re-use in paddy fields (Chowdary et al. 2004). Several mathematical models are available to describe water balance and behaviors of nutrients and pesticides in flooded rice fields. Some models describing the fate of nitrogen in rice fields focus on various processes taking place in flooded water: PADDY (Pesticide Paddy Field Model) (Inao and Kitamura 1999), PCPF-1 (Pesticide Concentration in Paddy Field, v.1) (Watanabe et al. 2007), RICEWQ (Rice Water Quality) (Williams et al. 1999; Karpouzas and Capri, 2006), and PADDIMOD (Jeon et al. 2005), while others describe mass transport in flooded water and the soil underneath. Chung et al. (2003) developed GLEAMS-PADDY model to describe nutrient loading in surface water and groundwater bodies. Chowdary et al. (2004), developed and applied a simple model for assessing the concentration of nitrates in water percolating out of the flooded rice fields. Tournebize et al. (2006), developed a coupled model (PCPF-SWMS) for simulating the fate and behavior of pollutants in water and soil of paddy fields. In GLEAMS-PADDY model, (Chung et al. 2003), N balance is separated into NH4-N and NO3-N balance and applied to ponding water and underlying soil. PADDIMOD (Jeon et al.

2005), describes N balance as the total inorganic N without focusing on NH4-N and NO3-N balance separately.

Through the literature, no study has been done yet in Malaysia for modeling solute transport for better fertilizer utilization towards improving water productivity and surface water pollution control in paddy fields. After application of fertilizers to the field, it dissolves, transports over the land surface and infiltrates into the soil by irrigation water. In deep soil layer, the HYDRUS-1D model can demonstrate appropriately the distribution of fertilizers through the gravitational one-dimensional flow (Tafteh and Sepaskhah, 2012). Numerical modeling has an important significance for improving fertilization methods (Abbasi et al. 2003) and reducing agricultural non-point source pollution attributable to improper fertilization (Bradford and Katopodes, 1998). Thus, it's very important to establish an improved fertilizer use to the governmental authorities and farmers.

1.2 Problem Statements

Food security is key global challenges. By 2050 the world will need to increase crop production to feed its projected 9 billion people (FAO, 2009). Climate change brings a serious impact on water resources, which affects the food security. Therfore, the rice production system must enable to respond to challenges posed by the effects of climate change on precious land and water resources.

It is well understood that over fertilization is a major problem in intensive agricultural production areas, resulting in the enrichment of air, soil, and water with reactive nitrogen leading to the impairment of ecosystem functions. The over-fertilization entails unnecessary economic expenditure for farmers. Nitrogen loss from agricultural fields is the main cause of eutrophication. Few studies have determined the efficiency of N use and loss of paddy fields (Yang et al. 2014) and fewer studies have focused under flooded condition (Kiran et al. 2010). The excessive N and P fertilizer use with decreasing fertilizer use efficiencies in agriculture has resulted in large amounts of N and P elements entering ambient water bodies and the atmosphere through various means (Xing and Zhu 2000; Yoshinaga et al. 2007; Ni et al. 2007; Li et al. 2008). Meanwhile, the transport of agro-chemicals from paddy fields pollutes the lakes and streams which lead to harm human health.

Due to the dynamic nature of paddy fields, N transport and transformation process are complex and difficult to understand. Quantification of water flow and nutrient losses in rice field becomes a challenge as rice is highly water and nitrogen demanding crop, thus, play key role for contributing pollutants in both surface and subsurface waters. In addition, rice field can lead a considerable nutrient loss by leaching under irrigated conditions and excess use of fertilizers. Indeed, no study is reported yet on this important aspect in Malaysia. Thus, this study focused to

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develop the better fertilizer utilization for improving water productivity and surface water pollutant control.

1.3 Aim and Objectives

The main objective of this study is to develop the improved fertilizer use model for rice production through the investigation of intensive water and solutes balance model integrated with 1-D solute transport numerical model. The specific objectives are:

1. To analyze water balance components in modeling solute transports in growing paddy field.
2. To estimate nutrients (N, P, and K) loads and water quality parameters from paddy fields to surface and subsurface water systems.
3. To characterize the spatio-temporal dynamics of nutrients using the HYDRUS-1D numerical model in paddy fields, and
4. To develop empirical models for the better utilization of nutrients in a rice-production system using EC and fertilizer application date.

1.4 Scope of the Study

This study focused on the modeling and development of improved fertilizer use for rice production under real paddy environment at Tanjung Karang Rice Irrigation Scheme (TAKRIS). An intensive investigation of water and solutes losses from surface and subsurface water throughout two consecutive rice-growing seasons was conducted. It was also within the scope of the study to utilize Hydrus-1D model, calibrate and validate it with the aim of using the model to predict water and solutes movement under different soil depths in the experimental plot. Multiple and polynomial regression analysis were performed, and different empirical equations were developed to estimate EC, T-N, T-P and K in the experimental plot. The main focus of the field experiments was the development of empirical equations to predict nutrient (N, P and K) concentrations at the surface, subsurface and drainage water for the better use of fertilizers.

1.5 Limitations on the Scope of the Study

Although the study has achieved its objectives as set out, the following limitations on the scope of the study are highlighted. First, the major limitation of the study is that the field investigation has been carried out in a specific paddy plot for two seasons in a year only. Secondly, the validation was not possible due to the climatic variations between two rice growing seasons. Thirdly, the mainitaining the standing water depth was not possible in a single plot. Finally, only one set porous cup with

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tube installed at different depths in a paddy field. It could be better if they would be installed at three different locations in the paddy field.

1.6 Organization of the Thesis

Chapter one focuses on the general introduction to the work, gives the statement of the problem, the objectives of the study, scope and limitation of the study and the thesis outlined. Chapter two contains literature review which discusses challenges of rice production in Malaysia, estimation of water balance component analysis from paddy field, solute transport from agricultural fields, methods of reducing fate and solute transport from agricultural fields, in particular, paddy fields. It also contains different surface and subsurface models such as LEACHM, SWAP, PCPF, VS2DT and HYDRUS-1D to simulate water flow and agrochemical (N, P and K). Chapter three discusses the location, soil and climate conditions within the study area. It further describes the description of the experimental setup, sample collection, lab tests, estimation of water balance components, solute transport analysis, development of statistical models, and utilization of Hydrus-1D procedures. Chapter four comprises of the results obtained and their discussions. Chapter five contains the conclusions drawn from the entire work, the major research findings and the recommendations of the further studies. At the end, a short bio-data of the candidate and a list of publications from the study are presented.

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