IMPACTS OF SYSTEM OF RICE INTENSIFICATION FARMING ON MARGINAL LAND

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IMPACTS OF SYSTEM OF RICE INTENSIFICATION FARMING ON MARGINAL LAND

ABSTRACT

Soil and water quality plays a vital role in crop yields. However, with degradation of soil and water quality due to extreme weather, excessive chemical inputs and lack of agricultural land, paddy production in Malaysia remained stagnant over the past decade. Shifting agriculture on marginal (infertile) land is currently one of the options to mitigate this problem. However, a good farming management is crucial in conducting any development on marginal land for agriculture. Hence, this study focuses on assessing soil and impounded water quality for marginal soil under the system of rice intensification (SRI) farming method. The soil suitability of this land for crop growth was found poor due to weathering process and deteriorating of soil fertility. Therefore, this study aimed at improving the quality of marginal land through the environ-friendly system of rice intensification (SRI) method. SRI is an agroecological method that helps to increase the productivity of paddy farming by changing the management aspects of crops, soil, irrigated water and nutrients, which are hypothetically able to provide better crops. Soil and impounded water quality under five farming stages during SRI method (land preparation, transplanting, water circulation, fertiliser management and harvest) at 12 experimental paddy plots were analysed. Overall qualities of the soil and impounded water by SRI method have been significantly improved (Kruskal-Wallis test at probability level = 0.05). Moreover, limit of the optimum nutrient requirements was complied. When SRI performance was compared to the secondary data of conventional farming method, SRI was found improving its impounded water quality. Therefore, it can be concluded that SRI method can be used to improve the marginal soil for paddy plantation.

Keywords: system of rice intensification, marginal land, soil and water quality

IMPAK PENANAMAN PADI SECARA INTENSIF KEATAS TANAH MARGINAL

ABSTRAK

Kualiti tanah dan air memainkan peranan penting dalam pertumbuhan tanaman. Walaubagaimanapun, degradasi kualiti tanah dan air disebabkan oleh iklim ekstrim, penggunaan bahan kimia yang berlebihan dan kekurangan tanah untuk pertanian menyebabkan produksi padi di Malaysia kekal genang untuk beberapa dekad kebelakangan ini. Kaedah mitigasi adalah salah satu cara untuk membangunkan tanah marginal (kurang subur) untuk pertanian. Usaha ini memerlukan pengurusan kaedah pertanian yang bagus. Kajian ini tertumpu kepada penilaian kualiti tanah dan air bagi sawah padi di tanah marginal yang diusahakan dengan kaedah penanaman padi secara intensif (SRI). Kesesuaian tanah untuk pertumbuhan pokok adalah rendah disebabkan oleh proses luluhawa yang tinggi dan kemerosoton kesuburan tanah. Tujuan kajian adalah untuk meningkatkan kualiti tanah marginal melalui kaedah SRI yang merupakan satu kaedah pertanian agroekologi. Kaedah ini akan membantu meningkatkan produktiviti apabila cara pengurusan tanaman, tanah, air dan nutrient dan persekitaran yang lebih baik dijalankan. Kualiti tanah dan air dianalisis bagi lima peringkat penanaman SRI (penyediaan tanah, mencedung, pengurusan air, pembajaan dan penuaian) di 12 plot ekperimen. Analisis kualiti tanah dan air di sawah padi menggunakan kaedah SRI menunjukkan penambahbaikkan yang signifikan (analisis Kruskal-Wallis dengan tahap kebarangkalian = 0.05). Had optimum keperluan nutrien dalam tanah juga dapat dicapai. Apabila dibandingkan dengan kaedah pertanian secara konvensional, SRI didapati dapat meningkatkan kualiti air di plot padi. Secara keseluruhan, kaedah SRI boleh digunakan untuk menambahbaik tanah marginal untuk pertanian padi.

Keywords: penanaman padi secara intensif, tanah marginal, kualiti tanah dan air.

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LIST OF SYMBOLS

^{o} C	:	Degree Celsius
µS/cm	:	Micro Siemens per centimetre
╨	:	Paddy seedling
Cm	:	Centimetre
dS/m	:	DeciSiemens per metre
Ha	:	Hectare
meq+/100 g	:	Milliequivalent of hydrogen per 100 g of dry soil
mg/L	:	Milligrams per litre
ppm	:	Parts per million
S.D	:	Standard deviation

LIST OF ABBREVIATIONS

CEC	:	Cation exchange capacity
CIIFAD	:	Cornell International Institute for Food, Agriculture and Development
CO_2	:	Carbon dioxide
DAT	:	Days after transplanting
DEM	:	Digital elevation model
DO	:	Dissolve oxygen
DOA	:	Department of agriculture
EC	:	Electrical conductivity
FM	:	Fertiliser management
GIS	:	Geographic information system
GPS	:	Global positioning system
HCI	:	Hydrochloric acid
HDPE	:	High-density polyethylene
HRU	:	Hydrological response unit
HV	:	Harvesting
IADA	:	Integrated Agriculture Development Authority
LP	:	Land preparation
MADA	:	Muda Agricultural Development Authority
MARDI	:	Malaysian Agriculture Research and Development Institute
N	:	Nitrogen
N:P:K	:	Nitrogen : Phosphorus : Potassium
NH_4-N	:	Ammoniacal nitrogen
NUE	:	Nutrient uptake enhancer
NWQS	:	National Water Quality Standards

OC	:	Organic carbon
P	:	Phosphorus
pH	:	Potential of Hydrogen
PO_4	:	Phosphate
SRI	:	System of rice intensifications
SWAT	:	Soil and Water Assessment Tool Model
TP	:	Transplanting
UKM	:	Universiti Kebangsaan Malaysia
WC	:	Water circulation

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Rice is a strategic agricultural industry in Malaysia. Other than being the source of staple food, the industry also provides livelihoods to more than 300,000 paddy farmers in Malaysia (Mohd Rashid & Mohd Dainuri, 2013). The Government of Malaysia is committed to Green Revolution in reforming paddy plantation from traditional to modern agriculture through the introduction of machinery and package with the use of high production paddy variety and other biochemical inputs such as fertilisers and herbicides supported by infrastructure facilities (Hussin & Mat, 2013).

In 2015, the Ministry of Agricultural and Agro-based Industry of Malaysia aimed to achieve full self-sufficiency level (SSL) in paddy production by the year 2020 (Riceoutlook, 2015). In order to achieve full SSL target, paddy production should reach the average yield of 7 tonnes per hectare. Thus, more workable solutions need to be carried to increase the paddy production to achieve the SSL target.

Currently, land area for paddy cultivation in Malaysia has been “fixed” to eight main granary areas (Chan & Cho, 2012). Xavier *et al.* (1996) explained that lands suitable for paddy cultivation in Malaysia have been utilised and there is limited or no scope for further expansion in the area for paddy production. In a larger context, Blum (2013) described that loss of fertile land for agriculture cultivation was caused by inadequate soil management through urbanisation and industrialisation. Limited land resources have sparked the initiative of remediating the marginal lands for paddy cultivation. Researchers have recommended utilising the marginal or idle land for cultivations to meet the increased demand (Merckx & Pereira, 2015; Shahid & Al-Shankiti, 2013). An earlier suggestion by Teh (2010) mentioned that the 100% self-sufficient level could be achieved even at 2% increase in paddy productivity per year with an expansion development for paddy area cultivation in Malaysia.

1.2 Problem Statement

Several challenges are currently faced by Malaysia's paddy plantation for the past several years to achieve 100% self-sufficient status. Among these challenges are; the effects of extreme weather by the climate change, deterioration of soil quality by the long-term irrigation process and limited agriculture land area. All of these factors have affected the overall paddy production (Herman *et al.*, 2015). To address these effects by the mentioned issues, paddy farmers have increased the dosage of chemical fertiliser to replenish soil nutrients leading to a better crop yield. However, high amount of N-P-K elements by the fertilisers is not completely absorbed by the paddy crops. Therefore, excessive nutrients would be either remained or accumulated in the soils and latter leached or transported to the surrounding water bodies, which would eventually cause environmental pollution.

Changes in soil and water qualities have gained attention in the recent years as a result of environmental issues related to soil and water degradation and production sustainability under different farming systems. Several studies reported that the degradation of soil quality is a key factor for the observed declining or stagnant paddy yield (Bhandari *et al.,* 2002; Ladha *et al.,* 2003). Meanwhile, many studies reported that intensive paddy cultivation activities could influence impounded water quality (Harlina *et al.,* 2014; Haroun *et al.,* 2015; Tirado *et al.,* 2008; Varca, 2014). Major nutrients that degrade water quality through eutrophication are nitrogen and phosphorus from excessive use of external inputs in the paddy fields (Chislock *et al.,* 2013). Therefore, maintaining a healthy soil and impounded water quality in paddy plots is crucial as they play pivotal roles in achieving a promising yield of crops (Suresh & Nagesh, 2015; Talpur *et al.*, 2013).

Nevertheless, developing marginal lands into good cultivation sites requires extra effort. Shahid and Al-Shankiti (2013) explained that marginal lands do not have sufficient capacity for food production unless significant management efforts are made to improve soil quality. Due to poor soil condition on marginal lands, water quality should be considered as chemical pollutants from cultivation practices may impose a high risk to impound and groundwater pollution. Therefore, the challenge lies in finding a holistic and sustainable farming approach able to increase paddy production and help to avoid any environmental effects as well as encourage co-benefits.

Many existing and new methods have been developed to increase paddy production. The system of rice intensification (SRI) method (Uphoff *et al.*, 2011) is one of them. It is a set of farming management guidance or practices established by many years of paddy research. It can provide better growing conditions for paddy crops. SRI has emerged as a set of guiding principles that can maintain high yields through stronger and healthier crops while reducing dependency on external inputs. SRI is founded on the idea that the use of chemical fertilisers and herbicides can be substituted with environmentally sustainable agronomic management practices such as weeding and manure application (Surridge, 2004). In addition, SRI method uses lesser water to maintain soil moisture. It also practices the early transplanting seedling at a young age with wider and single spacing between seedlings.

SRI method is increasingly recognised worldwide as a suitable model for creating environmental, economic and social sustainability in agriculture. In recent years, studies have proven the advantages of SRI method such as cost-effectiveness in reducing water consumption (Ndiiri *et al.*, 2012; Uphoff *et al.*, 2011), balancing ecosystem and being environmentally friendly (Doni *et al.,* 2015; Uphoff & Dazzo, 2016). SRI method increases the resistance towards crop diseases and protects the soil and natural ecosystem (Anas *et al.,* 2011). In addition, as SRI method practices organic farming management, it provides better quality food which is safer and healthier (Othman *et al*., 2010).

SRI method has been proven to improve paddy soil and increase yield in several tropical countries compared to conventional rice production methods (Barison & Uphoff, 2011; Chapagain *et al.,* 2011; Komatsuzaki & Syuaib, 2010; Nissanka & Bandara, 2004; Thakur *et al.,* 2010). In Malaysia, SRI has been implemented in several regions include Selangor, Melaka, Kelantan and Johor (Doni *et al.,* 2015; Marinah & Mohd Hafizuddin, 2013; Norela *et al*, 2013; Shaidatul Azdawiyah *et al.,* 2014). These studies have reported the increase of paddy yields.

Not many reports have mentioned about the effectiveness of SRI on marginal land. This study attempted to improve the marginal land through the effectiveness of SRI method. Therefore this study, SRI method was tested onto the abandon marginal land in Kampung Belantik, Sik, Kedah. The effectiveness of SRI method in terms of improving marginal soil and impounded water in paddy plots is also explained in this study.

1.3 Aim and Objectives

This aim of this study is to improve the quality of marginal land through the environ-friendly system of rice intensification (SRI) method. This aim was accomplished by fulfilling the following objectives;

i. To characterise the soil and impounded water quality for marginal soils in abandoned land.

ii. To establish the relationship between soil and impounded water quality, and

iii. To run the simulation in characterising the parameters for improving soil and impounded water quality using Soil and Water Assessment Tool (SWAT) model.

1.4 Scope of Work

The extent of the study focuses on the following points:

i. Preparation of experimental paddy plots and the following paddy farming process.
ii. Collection of soil and impounded water samples before and during SRI method. Chemical analysis in the laboratory for the quality of soil and impounded water.
iii. Statistical analysis for the quality of soil and impounded water under SRI method. Literature review study on conventional paddy farming for the quality of soil and impounded water status.
iv. Cold-run simulation of SWAT model for quality of soil and impounded water under SRI method.

The overall scope of this study is based on its aim and objectives (Figure 1.1). SRI farming method plays a vital role in the whole study design. Soil and impounded water quality during all stages of SRI method (land preparation stage, transplanting stage, water management stage, fertilisation stage and harvesting stage) was assessed. Comparison studies were performed on the soil and impounded water quality results under SRI method with a) soil quality status before SRI and b) soil and impounded water quality in the conventional farming method.

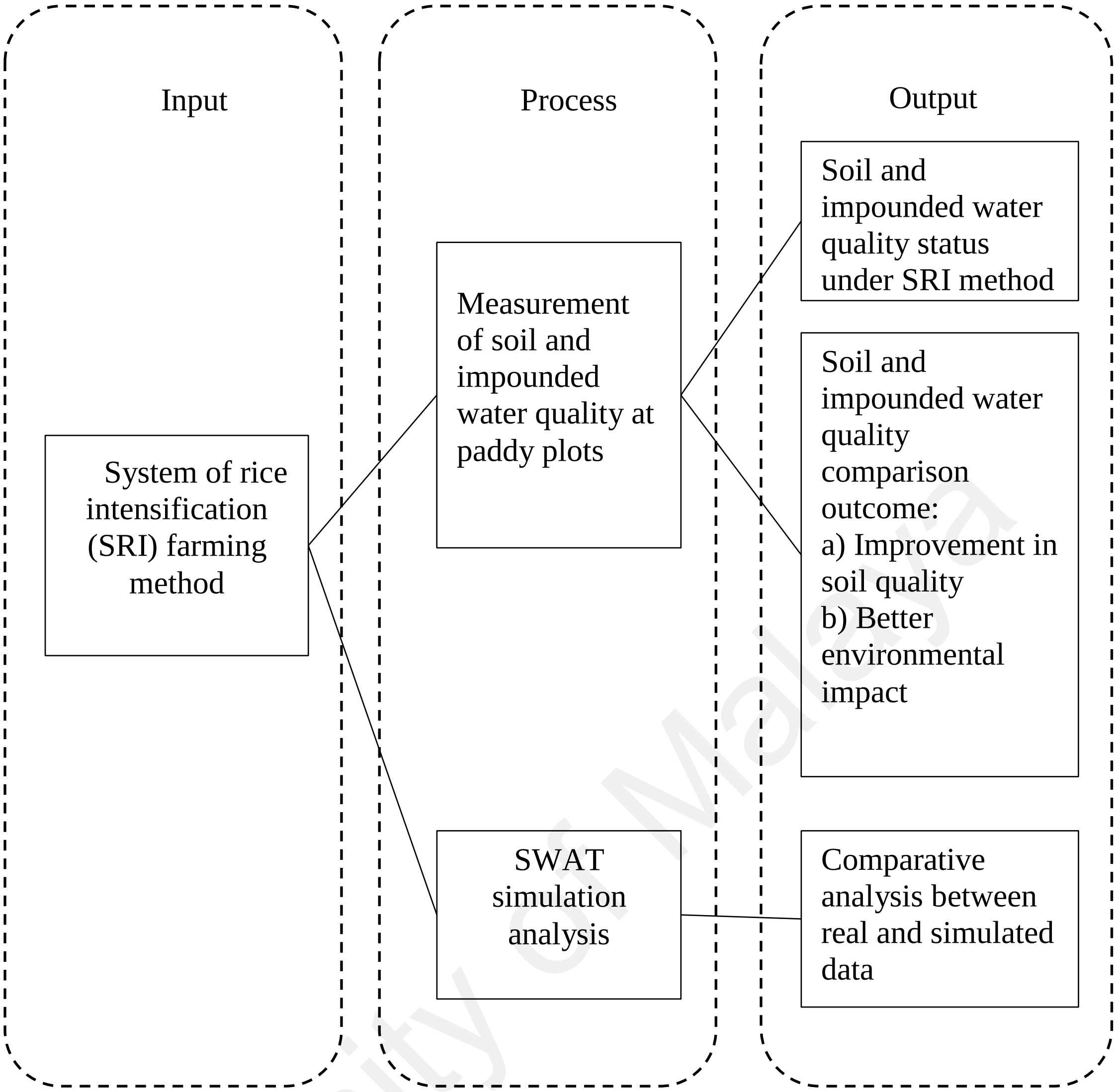


Figure 1.1: Summary on scope of work

In addition, with soil and impounded water quality during all SRI stages as mentioned above, this study has included a cold run for SWAT analysis. SWAT analysis was carried out in similar agriculture land use in several other countries including China and Korea, yet none has been tested in Malaysian paddy cultivation. This cold-run was only utilised for qualitative comparison.

CHAPTER 2: LITERATURE REVIEW

Areas covered in this chapter include a brief introduction on paddy cultivation in Malaysia, its challenges that focus on environmental issues as well as an introduction for degradation of abandoned land and impacts. Next is about the system of rice intensification (SRI) method; this includes principles, benefits, impacts review and the expansion of SRI method in Malaysia. In addition, literature review covers a brief introduction on the soil and water assessment tool (SWAT) model.

2.1 Paddy Cultivation Scenario in Malaysia

More than 90% of rice are produced and consumed in Asia (McLean *et al*., 2013) comprising 80% of the world's production and consumptions (Abdullah *et al*., 2006). In terms of food consumption, what distinguishes Asia from the rest of continents is that ASEAN countries depend greatly on rice as the staple food for the majority of the population. Majority of the production in the region emanates from Indonesia, Vietnam and Thailand. These major producers are accounted for approximately 71% of total rice production in 2015 (Department of Statistics Malaysia, 2016) as shown in Figure 2.1. In comparison to other countries, Malaysia produces only 1% from the total paddy production in South-east Asian countries in 2015 behind Cambodia (4%) and Laos (2%).

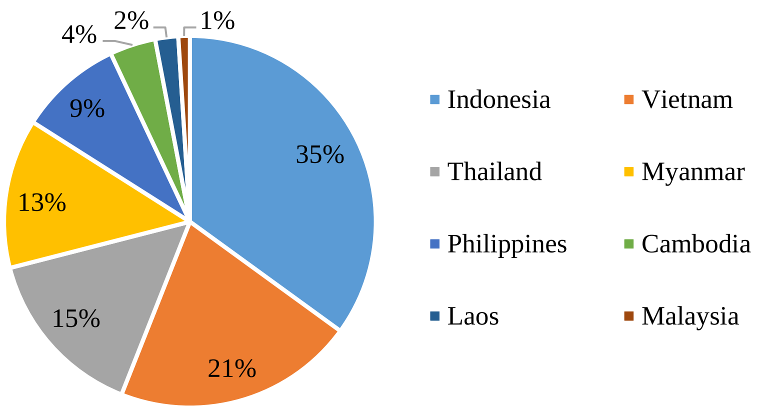


Figure 2.1: Breakdown of paddy production for selected ASEAN countries (Department of Statistic Malaysia, 2016**)**

In Malaysia, paddy is cultivated as a rain-fed or irrigated lowland crop (Herman *et al.*, 2015). In Sabah and Sarawak, dry land/hill paddy cultivation is still prevalent. Statistical data in Malaysia revealed that in 2010 alone, more than 300,000 paddy farmers relied on paddy farming as their main source of income (Mohd Rashid & Mohd Dainuri, 2013). These farmers grow paddy on a small scale of land with an average farm size of 2.5 ha/farmer (Mohd Rashid & Mohd Dainuri, 2013).

Paddy areas in Malaysia are mostly located in eight main granaries and several small granaries across the peninsular as shown in Figure 2.2. 'Granary Areas' refers to major irrigation schemes (areas greater than 4,000 hectares) and recognised by the government in the National Agricultural Policy as the main paddy producing areas (Department of Agriculture Malaysia, 2012).

These eight granary areas in Malaysia include Muda Agricultural Development Authority (MADA), Kemubu Agricultural Development Authority (KADA), Kerian-Sg.Manik Integrated Agricultural Development Area (IADA KSM), Barat Laut Selangor Integrated Agricultural Development Area (IADA BLS), Pulau Pinang Integrated Agricultural Development Area (IADA P. Pinang), Seberang Perak Integrated Agricultural Development Area (IADA Seberang Perak), Northern Terengganu Integrated Agricultural Development Area (IADA KETARA) and Kemasin Semerak Integrated Agricultural Development Area (IADA Kemasin Semerak). They are designated as a permanent rice producing areas fulfilling 75% of rice demands for the country (Vaghefi *et al.*, 2011).

Rice is the everyday diet for most Malaysians as well as being the symbolic crop in the traditional Malay culture. Paddy production plays an important role in the country's agriculture sector. Hence, the Malaysian paddy and the rice industry are often receive

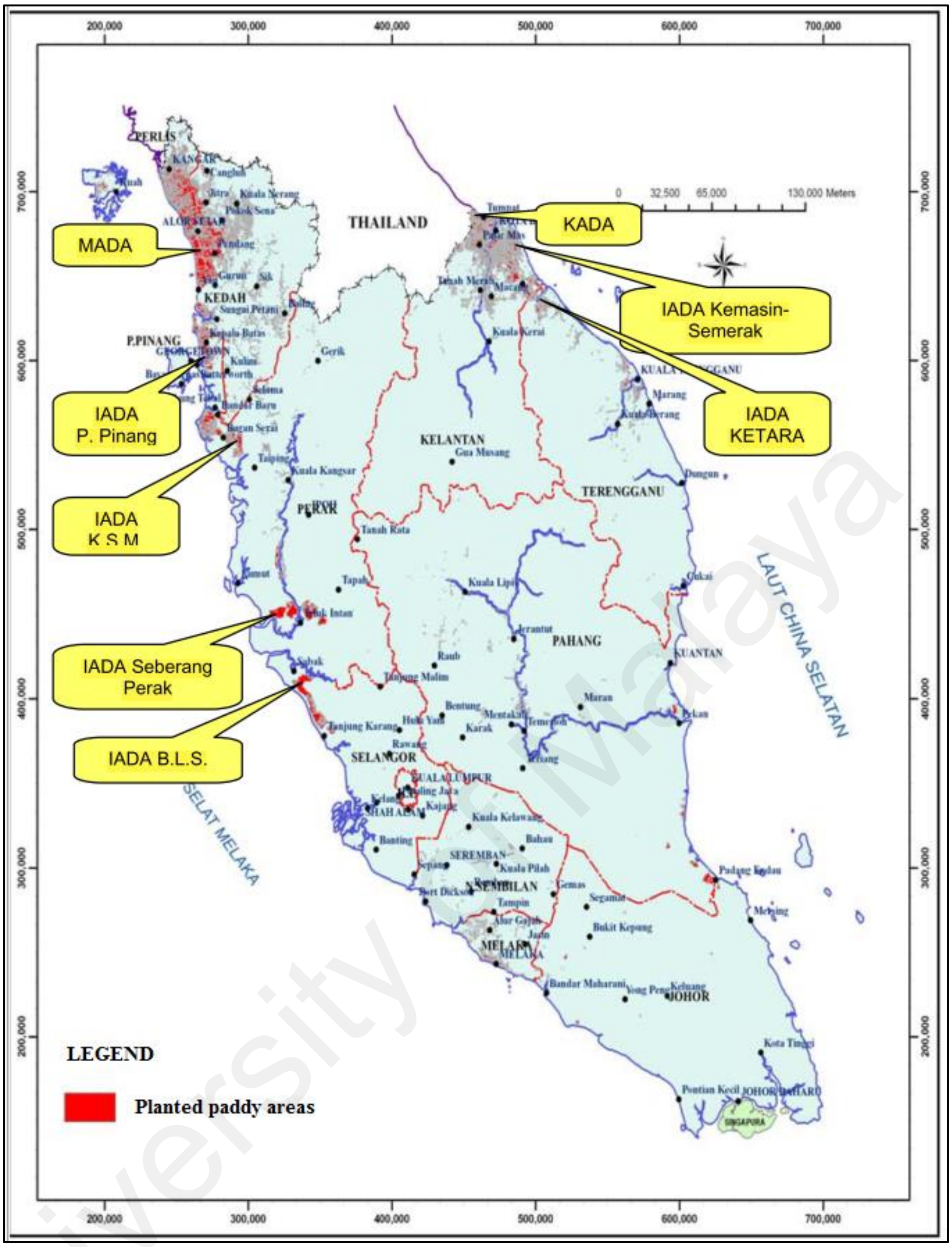


Figure 2.2: The eight granaries areas in Peninsular Malaysia (Department of Agriculture Malaysia, 2012)

substantial attention and seriously emphasised by the government due to its strategic importance as the country's staple food (Fahmi *et al.*, 2013). For the past 50 years, the Malaysian government has allocated billions of expenses to increase rice production. Government support includes R&D, credit facilities, subsidised retail price, guaranteed minimum price, extension support, fertiliser subsidies and irrigation investment (Fahmi *et al.*, 2013).

Malaysia's land areas for rice remained relatively constant at no more than 0.7 million hectares since the 1980s. Even though the land areas for paddy cultivation remained rather constant, Malaysia's paddy productivity has profoundly increased from 2.18 tonne/ha in 1961 to 4.03 tonne/ha in 2016 (Figure 2.3). This has eventually increased Malaysia's total paddy production each year. Since 1985, the average increase in total paddy production in Malaysia is about 27,300 tonnes per year.

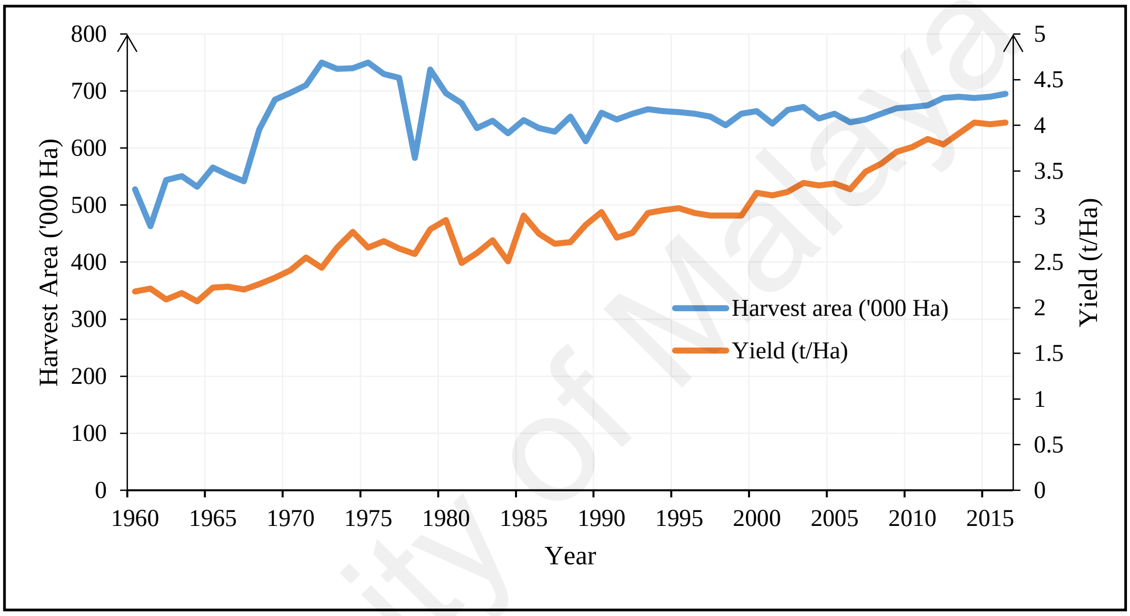


Figure 2.3: Paddy harvest areas and yield in Malaysia (1960-2016) (World Rice Statistic, 2016)

Although Malaysia's paddy yields have increased for the past several years, it is yet to satisfy the country's need to be fully self-sufficient in paddy production; hence, Malaysia is still importing rice from the neighbouring countries including Thailand and Vietnam (Freedman, 2013). Since the past several years, the Ministry of Agricultural Malaysia has set a target for the country to be 100% self-sufficient in terms of paddy productions. In order to achieve this goal, paddy production needs to be at an average of 7 tonnes/ha while the average current rate of paddy production is still relatively very low.

Realising that Malaysia is still not self-sufficient, the government has launched the National Agrofood Policy (NAFP) in 2011 (Bakar *et al.*, 2012). This policy focuses on increasing the efficiency of agro-food industry along the value food chain to make the sector more productive, competitive and knowledge intensive. With the NAFP established, it showcases the Malaysian Government commitment in ensuring sufficient supply of rice to the country.

2.2 Challenges in Paddy Cultivation in Malaysia

Extensive adoption of improved methods for production through favourable government assistance, new policy and the availability of agrochemical has maintained for paddy production in Malaysia. However, several reports have highlighted concerns and challenges for the long-term sustainability of paddy production faced by paddy producer countries (Godfray *et al.,* 2010; Iqbal & Amjad, 2012; Redfern *et al.,* 2012; Siwar *et al.,* 2014). These concerns are due to the stagnant or even declining yields, land degradation and environmental pollution in intensive irrigated paddy areas. In Malaysia, major challenges faced by paddy farmers include the limited agriculture land resources, impact from climate change, soil fertility and water quality degradation due to long-term and excessive chemical usage, poor water distribution and management as well as low water productivity (Alam *et al.,* 2012; Fuad *et al.,* 2012; Yusoff & Panchakaran, 2015).

2.2.1 Limited Agriculture Land Resources

Area growth for paddy cultivation is extremely limited in Malaysia for many years now (Figure 2.3). The possibility of increasing area for paddy cultivation is almost nil (Elisa Azura *et al.,* 2014), which is mainly because the arable land has been exhausted due to the rapid expansion of modern rice varieties since the Green Revolution (Tran, 1997). The Green Revolution is the beginning of reformation for paddy cultivation through the introduction of machinery and packages in the use of high production paddy variety with biochemical inputs (fertilisers and herbicides) supported by infrastructure facilities (Hussin & Mat, 2013). However, the Green Revolution, which is a technocratic style of development, has created enormous social and economic problems for the farming community (Irani *et al.*, 2001). Other reasons for limited land resources for cultivations are due to urbanisation and industrialisation (Blum, 2013) as well as the blooming of palm oil industry in Malaysia.

In addition, a study by Herman *et al.* (2015) explained that other land-related challenges paddy farmers in Malaysia faced are due to its natural geographically nature. In Malaysia, mostly paddy is cultivated as irrigated lowland (Figure 2.2); however, most of Peninsular Malaysia covered in tropical rainforest with mountainous areas. Hence, the paddy areas are constrained to the major eight granaries.

In respond to the scarcity of available land due to rapid urbanisation, industrialisation and the demographic pressure, farmers have been encouraged to exploit idle and marginal lands to increase rice production in meeting the demands. The expanding development on marginal lands is in line and has been the focus in the Malaysia's agricultural policies (Jamal & Yaghoob, 2014). Milbrandt and Overend (2009) characterised marginal lands as having poor soil physical characteristics or poor climate, which makes it difficult for cultivation. Herman *et al.* (2015) presented a map highlighting areas in Malaysia with major environmental problems and soil constraints that affect the current and prospects of rice agriculture in Malaysia (Figure 2.4).

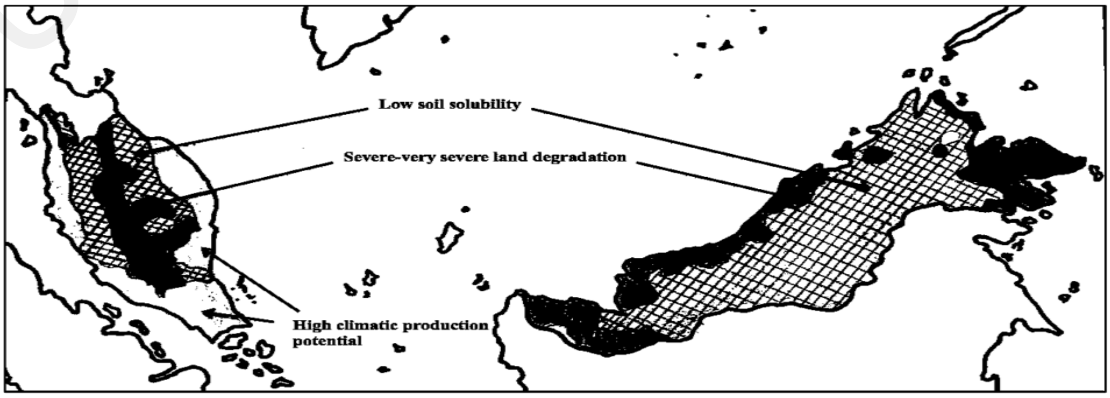


Figure 2.4: A schematic map of the main environmental constraints in Malaysia (Herman *et al.*, 2015)

Figure 2.4 displays the highlighted areas in Malaysia with poor soil condition and facing severity to very severe land degradation covering from the centre to up north of Peninsular Malaysia. The highlighted areas are mountainous regions and the majority of soils are made of ultisols and oxisols soils. These soils are considered as highly weathered with low soil solubility and relatively low native fertility. These kinds of soil have pH value less than 5, low in cationic exchange capacity and a high fix amount of fertiliser-P (Shamshuddin & Fauziah, 2010). Therefore, ultisols and oxisols soils are unsustainable for long-term agriculture use without the use of fertiliser and lime to gain a better rate of yield production.

However, Milbrandt and Overend (2009) highly suggest that even though the lands are less productive, marginal lands used to grow crops can provide additional environmental and social benefits. In scientific articles reported by Fargione *et al.* (2008) and Tilman *et al.*(2009), due to relatively low soil organic content and weak ecosystem services in marginal lands, growing crops on such lands can minimise the potential of long-term carbon debt and biodiversity loss. Other environmental benefits of crop production on marginal lands with sound management practices could potentially increase soil carbon sequestration, support ecosystem services and at the same time improve soil and water quality (Johnson *et al.,* 2007; Lal, 2004; Nelson *et al.,* 2008; Zhang *et al.,* 2014).

2.2.2 Climate Change

Many studies have been conducted on the impact of climate change on the agriculture production. Redfern *et al.* (2012) explained that since most of the Southeast Asian countries economies rely on agriculture as primary income, climate change will be a critical factor affecting the productivity in the region. The rise of temperatures attributed from extreme climatic events such as heavier rainfall and drought (Herman *et al.,* 2015) may cause low paddy production due to the reduction rate of photosynthesis (Li &

Wassmann, 2010; Raziah *et al.*, 2010). The level of environmental stress has also increased due to extreme rainfall variability, thus affecting the capability of the system to maintain productivity (Tisdell, 1996). A recent study by Alam *et al.* (2010) found that a 1% increase in temperature can lead to a 3.44% decrease in current paddy yield and 0.03% decrease in paddy yield in the next season. Whereas a 1% increase in rainfall can lead to 0.12% decrease in current paddy yield and 0.21% decrease in paddy yield in the next season.

Other constraints to the paddy production from the rising of sea level due to climate change include the increased salinity in coastal granary areas from seawater intrusion (Herman *et al.*, 2015) as paddy is considered moderately sensitive to salinity (Redfern *et al.*, 2012). According to Zeng and Shannon (1998), high soil salinity can limit paddy growth resulting in yield losses of more than 50%. Therefore, the climatic changes impose significant threats to the agricultural sustainability in Malaysia; hence adaptation and mitigation on better approaches are much needed by the paddy farmers.

2.2.3 Excess of Chemical Inputs

Farmers are driven to confront the inevitable prospect of growing under unfavourable conditions due to changing patterns of agriculture land use and effects of climate change. Realising this, paddy farmers responded by adopting a higher usage of chemical fertilisers while neglecting some essential microelements to increase paddy yield (Liew *et al.*, 2010; Tran, 1997; White, 2006). Figure 2.5 shows the increasing trend of fertiliser consumption by paddy farmers in Malaysia from 1990 to 2013.

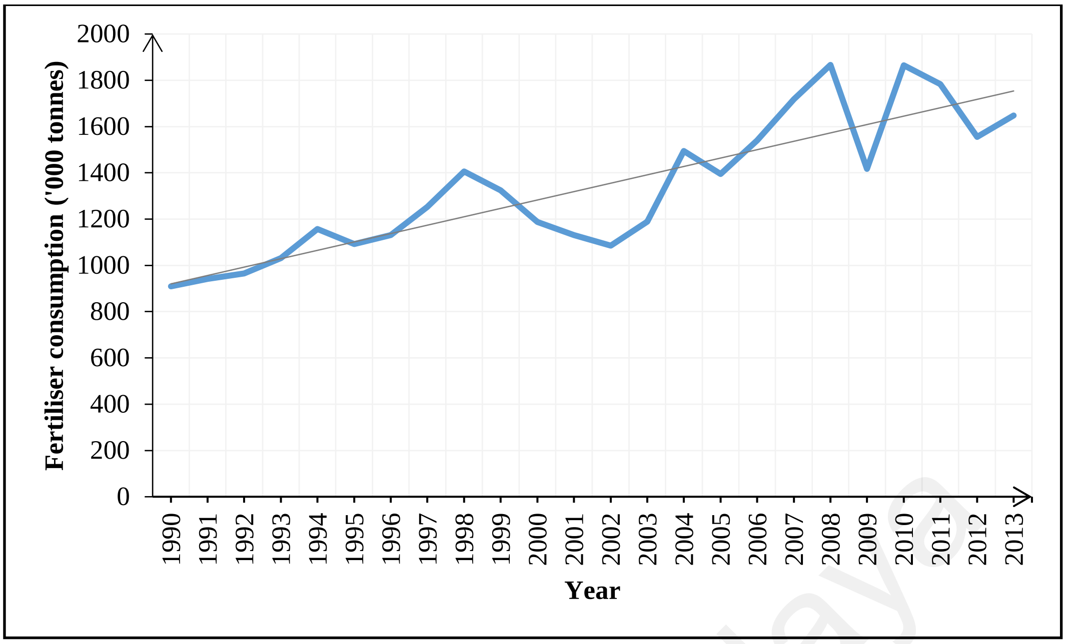


Figure 2.5: Fertiliser consumption for paddy cultivation in Malaysia (World Rice Statistic, 2016)

Despite that, a life cycle analysis study on paddy cultivation in Malaysia by Yusoff and Panchakaran (2015) discovered that most paddy farmers do not seem to know the appropriate amount of fertiliser application. From the study, the result demonstrated that the quantity of chemical fertiliser used was exorbitant (more than 60% than the recommended quantity). The main concern circulating paddy researchers is the effectiveness of increasing chemical fertiliser approach.

Chaudhury *et al.* (2005) reported that the recommended dose of chemical fertiliser alone does not sustain productivity under the continuous intensive farming system. However, the inclusion of organic amendments may help to improve physical properties, biological status of soil and soil fertility as well as crop yields. Several publications have appeared in recent years comparing the effectiveness of chemical fertilisers towards paddy yield. Results indicated that higher yielding can be only achieved by integrating chemical fertilisers with organic manure, while the use of chemical fertiliser alone has a low significant impact on paddy yield (Pan *et al.*, 2009; Satyanarayana *et al.*, 2002; Siavoshi *et al.*, 2011).

A study by Tirado *et al.* (2008) for paddy cultivation in Thailand also presented low yielding production despite a massive increase in chemical fertiliser usage. The study also explained that there was a tremendous loss of fertilisers into the environment due to imbalance use and poor management. In Malaysia, the same finding was achieved where combination of organic amendments with chemical fertiliser gave significant effect to paddy yield (Hoe *et al.,* 2015; Liew *et al.,* 2010; Naher *et al.,* 2016; Sharifuddin *et al.,* 1996).

These improper and excessive fertilisers that have not been absorbed by paddy crops in a long–run will alter and threaten the environment ecosystem. Microelements in the soil became deficient as it was neglected and compensated with higher application of chemical fertiliser. Hence, this will cause an imbalance in soil nutrient. Soil will also face nutrient toxicity and soil physical deterioration (Baishya, 2015; Tran, 1997; Varca, 2002). In high productivity capacities irrigated regions, excessive fertilisers and pesticides use often leads to the accumulation of nitrate and phosphate in soil, alga blooms and eutrophication in both groundwater and impounded waters (Ishii *et al.*, 2011; Leinweber *et al.*, 2002; Roth *et al.*, 2011). Other than that, excessive chemical fertiliser runoff can cause ammonia volatilisation (Xu *et al*., 2012), water toxicity, salinity as well as water pollution (Haroun *et al.,* 2015; Lamers *et al.,* 2011; Nakasone, 2009; Varca, 2002).

Therefore, since further intensification of rice cultivation is inevitable, researchers must understand the negative environmental side-effects of increasing rice productivity in developing appropriate mitigation options. Intensification that depends primarily on the larger use of external inputs is not the only kind of intensification method available. There are other intensification methods to be considered under the rubric of agroecology (Altieri, 1995; Gliessman, 2014; Stoop *et al.*, 2002). Abraham *et al.* (2014) stressed that it is essential to seek other intensification approaches that use available natural resources including the species and genetic biodiversity found in nature.

2.3 Degradation of Abandoned Land and Impact

Recently, abandonment of agricultural land has been reported from many parts of the world and has become an increasing trend (Khanal & Watanabe, 2006; Prishchepov *et al.*, 2013; Rey-Benayas *et al.*, 2007). Higginbottom and Symeonakis (2014) used the definition by the Millennium Ecosystem Assessment in their study referring degradation of lands as "the reduction in capacity of the land to perform ecosystem goods, functions and services that support society and development". For the purpose of this study, this definition is relevant as it covers the ability of land to support primary production as the key ecosystem service. According to UNCCD (2017), only 7.8 billion hectares of land are suitable for food production globally with 2 billion hectares already degraded and these 500 million hectares totally abandoned.

Lim (2002) explained that Malaysia is also facing a threat related to land degradations, which can be found in fragile ecosystems such as steepland, mountainous areas land with shallow soils, mined land, peat land, land with acid sulphate soils and the poor sandy beach BRIS (beach ridges interspersed with swales) soils and areas under shifting agriculture. Different to other arid and semi-arid place, land degradation in Malaysia is due to extreme events of rainfall, which can badly damage unprotected areas especially hilly areas. This extreme weather condition can result in severe soil erosion and other associated problems such as siltation, water pollution and frequent flash floods. In addition, degradation in these ecosystems occurs due to land clearing activities and deterioration to the physical and chemical properties of soils (Lim, 2002).

Therefore, as land and water resources become less abundant (and often of lower quality), such resource scarcity places a great premium on improving the management of all natural resources available (Abraham *et al.*, 2014). Such sustainable management includes the re-utilisation of degraded or abandoned land in meeting food production demand as well as increasing the livelihood of the community (Khanal & Watanabe, 2006). It must be noted that mitigating poor quality degraded land demands extra effort in terms of technology and advance or suitable farming approaches. In recent years, an emerging cultivating approach has surfaced and gained attention among agriculture researchers and farmers particularly in Asia (Choi *et al.*, 2013; Doi & Mizoguchi, 2013; Ly *et al.*, 2012; Noltze *et al.*, 2012). This new approach is known as the system of rice intensification (SRI) (SRI-Rice, 2015).

2.4 System of Rice Intensification (SRI)

The system of rice intensification (SRI) is a climate-smart and agroecological methodology for increasing paddy productivity by changing the management of crops, soil, water and nutrients (SRI-Rice, 2015). SRI method also practices the use of lower purchased inputs and allows farmers to better utilise existing resources. Berkhout and Glover (2011) emphasised that SRI is a crop management portrayed as a more productive and more ecologically sustainable method for paddy cultivation. This method is also appropriate, accessible and beneficial for marginal farmers since it can achieve a substantial increase in productivity and grain yield without the need to improve seeds or chemical inputs (Berkhout & Glover, 2011).

SRI method emerged in the 80's at the humid highlands of Madagascar with annual rainfall mostly ranging from 1000 to >2000 mm on poor soils with low pH, low cation exchange capacity (CEC), low available phosphorus (P) and high concentrations of soluble ferum (Fe) and aluminium (Al) (Dobermann, 2004). SRI was first described in a Belgian technical journal Tropicultura in 1993 (Laulanie', 1993). It was known as the best practice method specifically intended to raise paddy yields for the smallholders who are not benefiting from the Green Revolution production practices. The Green Revolution is based on the use of improved varieties and purchased of external inputs of mineral fertiliser and crop protection chemicals (Uphoff *et al.,* 2008).

2.4.1 Principles of System of Rice Intensification (SRI)

SRI method is based on four main interacting principles ranging from early transplanting, single spacing and widely transplanting of seedling, application of organic compost and controlled water management. A brief explanation on the principles is given in Table 2.1:

Table 2.1: Principles of SRI method (SRI- MAS, 2016)

Principles	Explanation
Transplanting young seedlings. Establishing crops early and quickly where seedlings are transplanted at age 8-15 days old	To favour healthy and vigorous root and vegetative plant growth
Maintaining low plant density by single and widely spaced transplant of seedling	Allowing optimal development of each plant and minimise competition between plants for nutrients, water and sunlight.
Reducing and controlling the application of water	Providing only as much water necessary for optimal plant development and to favour aerobic soil conditions.
Enriching soils with organic matters	To improve nutrient and water holding capacity, increase microbial life in the soil and to provide better substrate for roots to grow and develop

(a) ***Transplanting young seedlings***

Transplanting seedling at an early age stage has been supported by many researchers (Pasuquin *et al.,* 2008; Mishra & Salokhe, 2008; Brar *et al.,* 2012). Laulanie' (1993) recommended transplantation of the seedlings during the third phyllochron at the stage when the plant has only two leaves to avoid reduction in subsequent tillering and root growth. Stoop *et al.* (2002) in his study on SRI method discovered higher yield production when seedlings are transplanted at the age less of than 15 days (before the start of the fourth phyllochron). This finding was then supported by Uphoff *et al.* (2011) where they explained that the farming method is able to preserve plants' potential for tillering and root growth that is compromised by later transplanting.

(b) ***Maintaining low plant density***

Better access to solar radiation for higher photosynthesis process as well as having more soil area around to draw nutrients are among the benefits of planting seedlings in wider spacing (Pandey, 2009). In addition, Pandey (2009) explained that the spacing is critical in modifying crop components influencing final grain yield that mainly depends on the root system activity. So, it can be suggested that wider spacing allows roots to abundantly grow along with the production of more tillers per plant. Several studies have been conducted in relation to wider spacing of rice seedling where long duration varieties perform better with wider spacing than short duration varieties under SRI method (Thakur *et al*., 2009 and Avasthe *et al*., 2012).

(c) ***Reducing and controlling the application of water***

Ramamoorthy *et al.* (1993) reported that 25-50% of water can be saved under farming method implementing intermitted water management without negatively affect paddy yield. This was supported by a study of Boonjung and Fukai (1996) explaining that crop growth is not harmed when exposed to limited water condition during vegetative stage. Other benefits of controlling water management into paddy plots include improves soil condition, stimulates tiller development and alters sink-source relationships.

(d) ***Enriching soils with organic matter***

Yang *et al.* (2004) reported that using organic matter instead of chemical fertiliser can bring beneficial effects to root growth by improving physical, chemical and biological environment in which root grows. A study by Sahrawat (2000) found that there is a significant decrease in root growth under continuous water logging condition, whereas under control water management, the application of organic matter improved root morphological characteristics and root activity of paddy crops. Many SRI advocates are promoting that the most extensive root system of SRI plants and the improved structure and biological condition of soil can be achieved by compost application, which provides an access to a much larger pool of nutrients (Pandey, 2009). Nevertheless, in a review study by Uphoff (2003), most SRI method studies on the advantages from using compost have been observed from factorial trials; however, if organic matter is not available, SRI practices can be also used successfully with chemical fertilisers.

Based on these principles, paddy farmers can adapt the recommended SRI method in response to their agroecological and socio-economic situations. SRI method adaptations are often made to accommodate changing weather patterns, soil conditions, water availability, organic inputs and the decision whether or not to practice fully organic agriculture (SRI-Rice, 2015). Differences in method approaches for paddy cultivation between SRI and conventional are shown in Table 2.2.

Table 2.2: Comparative method approaches between SRI and conventional farming (SRI- MAS, 2016)

Cultivation Practices	**SRI**	**Conventional**
Seed selection & preparation	Seeds are soaked for 24 hours before seeding to remove non-viable seeds.	Seeds are not selected or treated
Nursery management	Nurseries are not flooded and often raised beds.	Nurseries are flooded and densely seeded.
Age of transplanted seedling	Seedlings transplanted after 8 - 15 days corresponding to one to two-leaf stage.	Seedlings transplanted after 21-30 days occasionally up to 60 days.
Spacing	Hills are gridded with spacing of 25 cm x 25 cm or more.	Hills are 10- 15 cm apart in rows or irregular spacing.
Number crops per hill	A hill only support one individual; <16 crops per square metre.	A hill supports 3- 5 individuals; 130- 500 crops per square metre
Water management	Fields are alternately wetted and dried.	Fields are continuously flooded during a crop cycle.
Weed control	Soil is subsequently aerated via mechanical weeding.	Weeds are removed by hand or through the use of weedicides and herbicides.
Fertilisation	Organic matter forms the basis of fertilisation; chemical fertilisers are only used complementarily.	Chemical fertilisers are heavily used.

It should be noted that SRI is not a 'standard package' of specific methods, but rather represents an empirical method that may vary to reflect local conditions (Stoop *et al.*, 2002). Farmers have been encouraged to experiment in their fields to find the best suitable method in validating the practical relevance and risks associated with practising SRI method under specific local conditions. Variants of SRI method have been also tested in which only some of the core components practised (Dobermann, 2004; Ly *et al.*, 2012).

2.4.2 Review on System of Rice Intensification's (SRI) Benefits

According to the SRI International Network and Resources Centre, also known as SRI-Rice (2015), the benefits of SRI method have been demonstrated in over 50 countries (Appendix A). These benefits include 20 - 100 % or more increased yields of up to 90% reduction in required seed and up to 50% water savings (SRI-Rice, 2015).

Noltze *et al.* (2012) clarified that the impacts of SRI method are context specific and almost all studies on SRI method point at positive environmental and resource conserving effects due to reduced use of external inputs. Even though chemical fertilisers can be used in SRI method, some of the best paddy yield results are obtained just by enhancing soil organic matter (Uphoff & Randriamiharisoa, 2002).

Many studies revealed that soil quality increased by adding soil organic matter or crop residue (Mendoza, 2004; Singh & Singh, 1995). The source of soil organic matter is through the application of compost that helps to improve the structure, functioning and biological benefits of soil system in ways that chemical fertiliser cannot (Uphoff & Dazzo, 2016). Other environmental benefits from application of SRI method may affect water conservation, nutrient and soil organic matter dynamics, carbon sequestration, soil quality and productivity, weed ecology and greenhouse gas emissions (Belder *et al.*, 2005; Mishra *et al.*, 2006; Stoop *et al.*, 2002; Tuong & Bouman, 2003).

A study in Indonesia where SRI is introduced to farmers under a Japanese-funded irrigation management improvement project, farmers were advised to reduce their application of fertilisers (N:P:K). This suggested fertiliser application amount was half compared to that recommended by the government. The farmers were also advised to increase their inputs of organic matter. As a result, 50% of fertiliser use was reduced along with the irrigation application by 40%. This has caused more than 12,000 farmers to increase their paddy yields on average by 78% representing 3.3 tonnes/ha by changing to the suggested method during this study. All data are not from test-plot comparison but rather from 12,133 on-farm comparison trials conducted over six seasons covering a total area of 9,429 hectares (Sato, 2007).

Another conceptual theory suggested that SRI has the potential to boost yield in marginal soils with low nutrient availability and low potential for rice production. Findings from Turmel *et al.* (2011) revealed that a significant increase in yield was observed when SRI is implemented on highly weathered infertile soil rich in iron and aluminium oxides (Acrisols and Ferralsols). In contrast, there was no difference in yield between SRI and conventional farming method in more fertile favourable soils for paddy cultivation (Gleysols, Luvisols and Fluvisols). This finding was in conformity with the studies by Dobermann (2004) and Hengsdijk and Bindraban (2004) where SRI method showed little potential to increase yields in more favourable soils where rice is already grown near the yield potential.

Other recent study examining SRI method on marginal soil was also done by Subardja *et al.* (2016). The results showed that due to the application of organic matter in SRI method, soil biological properties increased as well as paddy growth and its production. Meanwhile, the organic matter used in SRI method had increased soil biodiversity as it provided better oxygen and nutrient for microbes compared to the flooded conventional method, hence better growth of paddy crops. Subardja *et al.* (2016) added that the increase of paddy production under SRI method was resulted from the watering management pattern that gives advantages to rice rhizosphere.

Reduction in the use of fertilisers will improve not only soil quality, but also water quality as less agrochemical fertiliser is used. A study on the effects of SRI method conducted at Kangwon National University in Korea found a significant reduction in pollutant in the water runoff from paddy fields. Furthermore, there were significant drops observed in suspended solids, chemical oxygen demand and total phosphorus content. Biochemical oxygen demand and total nitrogen were also reduced although it was not significant. In addition, with SRI in practice, the paddy crop's water requirement was reduced by 56% as reported by Choi *et al.* (2014).

In much sense, the rhetorical promise of SRI method satisfies the often conflicting objectives of agriculture development: large grain yields with few inputs, placing benefits commensurate with those achieved with green revolution technologies within reach of the poor while reducing environmental externalities and improving sustainability (McDonald *et al.*, 2006).

2.4.3 System of Rice Intensification (SRI) in Malaysia

In 2008, a group of professionals invited Dr.Norman Uphoff from Cornell International Institute for Food, Agriculture and Development (CIIFAD), Cornell University to Malaysia. This visit was to discuss SRI method with the Minister of Agriculture and others interested in giving more momentum to the paddy sector (SRI-Rice, 2015). Uphoff met with paddy researchers at Malaysian Agricultural and Rural Development Institute (MARDI), civil society representatives and the faculty of the National University of Malaysia (UKM) faculty members (SRI-Rice, 2015).

Following this visit in 2009, a number of researchers from UKM formed a research group dedicated to carry out a study on SRI method. Two locations namely Tanjong Karang and Beranang were identified as the first SRI method experimental plots in Malaysia. Despite several constraints, yields for the variety in Beranang were highly encouraging giving about 7 and 5 tonnes per hectare for MR219 and UKMR2, respectively, whereas the yield for Tanjong Karang was about 4 tonnes per ha for both varieties (SRI-Rice, 2015).

The emerging of SRI method in Malaysia is considered as much later compared to other Asian countries that have begun utilising the opportunities offered by the system of rice intensification (SRI) (Uphoff & Fisher, 2011). However, the interest in SRI method has rapidly grown within the government, universities, NGOs and private sectors after the first SRI method trial was initiated leading SRI researchers to ensure more cooperation in Malaysia than in some other places. Until now, several centres of paddy farming in Malaysia are implementing SRI method that can be found in Sabak Bernam, Selangor, Kampung Tunjung, Kelantan and Kampung Lintang, Kedah (SRI-Rice, 2015).

Stoop *et al.* (2002) suggested that SRI method is first needed to be understood in terms of a set of principles and a set of mostly biophysical mechanisms. SRI method should be tested under a range of different agroecological environments and on-farm participatory studies. A farming system approach would be required to validate the practical relevance and risks of SRI method before any attempts are made to promote their integration into specific production system. In Malaysia, even though SRI method has been introduced since 2009, no study on paddy soil quality improvement has been done on infertile soil of marginal land. Table 2.3 enlists the published research works on SRI method in Malaysia.

A handful of research papers based on SRI method in Malaysia have been published from 2012 to 2016. Most of these studies focused mainly on awareness and acceptance of SRI method in Malaysia, impacts of SRI on ecosystem and biodiversity as well as the effectiveness of SRI management in terms of paddy yield. On the other hand, studies on SRI impact on soil and impounded water quality especially on infertile soil of marginal land are still lacking compared to other countries such as Madagascar, Indonesia, Sierra, Leone, Myanmar and Philippines where such studies have been conducted (Dobermann, 2004).

Table 2.3: Published SRI-related studies works in Malaysia

Scope	Title	Author(s)	Publication year	Results
Agribusiness & marketing	Malaysian paddy farmers' awareness and perception towards system of rice intensification (SRI) practices: A preliminary study.	Nolila & Siti Samiha	2012	Results showed that 88% respondents interviewed are aware about the existence of SRI in their area. Further analysis revealed two factors namely low cost of production and sustainable farming that collectively described farmer's perception towards SRI practices. This shows that SRI covers both economic and environmental aspects of rice cultivation and should be adopted by all paddy farmers in Malaysia to overcome the issues of food security and water crisis.
Pest management	Diversity of pest and non-pest insects in an organic paddy field cultivated under the system of rice intensification (SRI): A case study in Lubok China, Melaka, Malaysia.	Norela *et al.*	2013	34 species representing 21 families and 8 orders of insect were recorded with most abundant insects order were Orthoptera (22.9%; 231 individuals) and the lowest was Diptera (2.3%; 23 individuals). In terms of feeding habits, herbivorous insects were the most abundant (65%) followed by carnivores (27%) and omnivores (8%). Results indicated that SRI has ensured a good balance between the populations of pests, beneficial insects as well as other insect's communities during various phases of paddy development without any loss in yield. These suggest that SRI is an effective way to conserve, use and enhance biodiversity crucial to sustainable food security.
Plant physiology	Physicochemical, vitamin B and sensory properties of rice obtained by system of rice intensification (SRI).	Haqim *et al.*	2013	Results showed that the weight of non-organic rice (21.2 mg) was significantly higher ($p \leq 0.05$) than SRI (19.7 mg) or conventional (19.4 mg). The amylose content of conventional rice was the highest (16.6%) followed by SRI (15.6%) and conventional organic rice (15.3%). Vitamin B1 and B3 contents of organic rice were higher compared to non-organic rice. Overall, the study concluded that rice cultivated using SRI resulted in comparatively better physicochemical characteristics and sensory quality compared to other methods.
Paddy production	Modelling and forecasting on paddy production in Kelantan under the implementation of system of rice intensification (SRI).	Marinah & Mohd Hafizuddin	2013	This study conclude that the composite forecast model of Holt's Linear and Damped Trend Exponential Smoothing are the best model to be used where it predicts a generally increasing pattern of Kelantan total paddy production for the next five years.
Agriculture & environment management	Comparison on methane emission from conventional and modified paddy cultivation in Malaysia.	Pardis & Hasfalina	2014	Results demonstrated that maximum methane emission was significantly lower in modified cultivation systems (MC) compared to conventional farming methods (C). Water management process was the main influencing factor providing the positive results in MC. It was concluded that using MC approach can provide a sustainable rice production system.
Agriculture & environment management	Impact of mulch on weed infestation in system of rice intensification (SRI) farming.	Aimrun *et al.*	2014	This study showed that using SRImat mulch was more effective to control weed for SRI farming. SRImat treatment had the lowest weed density, weed density ratio, weed dry weight and highest weed control efficiency of 98.50% indicating its effectiveness on weed suppression.
Agriculture management	Quality seed: An innovative sorting technique to a sustainable, uniform and effective seedling establishment in nursery for system of rice intensification.	Zubairu *et al.*	2014	This study aimed to create suitably seed sorting technique for SRI nursery revealing that 100% germination after 10 days was obtained from the sunken MR219 seeds collected in 80 g/L of NaCl solution. The percentage of sprouting was proven to be high from the sunken seeds obtained in 80 g/L with 100% sprouting success rate. A decrease in percentage (70%) has been revealed with increasing NaCl concentration from the seeds obtained in 120 g/L and also when it is reduced to 40 g/L, which reported 65% sprouting rate. This technical information serves as benchmark to practicing farmers stating that high concentration in NaCl does not only reduce the percentage of viable seeds, but also increase seedling preparation cost as well as entire production cost.

Table 2.3, continued

Scope	Title	Author(s)	Publication year	Results
Ecosystem	Impact of system of rice intensification (SRI) on paddy field ecosystem: case study in Ledang, Johore, Malaysia.	Doni *et al*.	2015	The study revealed that SRI significantly increased rice tiller's number, plant height, filled grains and 1000 grain weight, improved rice productivity up to 7.58 ton/ ha, increased the number of soil beneficial microbes as well as insect biodiversity. These results proved that SRI should be considered as a potential cultivation method for sustainable rice production.
Agriculture & environmental management	Influence of oil palm empty fruit bunch biochar on floodwater pH and yield components of rice cultivated on acid sulphate soil under rice intensification practices.	Rosenani *et al*.	2015	The study showed that by applying empty fruit bunch (EFBB) under SRI practices, grain yields, plant growth and number of tillers were significantly increased. Soil water pH increased from 3.5 to 6 with increasing EFBB application rates. Apart from improving soil chemical properties, the EFBB had reduced Al 3+ concentration and increased floodwater pH. This study presented that EFBB has the potential to increase yield and growth of rice cultivated based on SRI system.
Agriculture & environmental management	The value chain of system of rice intensification (SRI) organic rice of rural farms in Kedah.	Siti Norezam *et al*.	2016	This study found that implementing SRI practices had caused the value chain to be different from conventional paddy value chain in terms of actor and effect of middle man subject to the small scale paddy production. For organic rice value chain to become competitive, roles, activities and challenges were identified so that supports can be provided to farmers and other related parties in the value chain.
Agriculture & environmental management	SRI-Tray: Breakthrough in nursery management for the system of rice intensification.	Zubairu *et al*.	2016	The growth performance of seedlings was compared between SRI and conventional nursery methods. Results revealed that SRI-tray had the highest significant value for seedling height, leaf length and root length when compared with conventional practices. Meanwhile, the seed rate, nursery area and seedling age to support one hectare of planting area were found as 5.34kg, 36m2 and 8-10 days on SRI-tray against 15-50kg, 250 – 500m^2 and 15 – 30 days on conventional practices. The water management was found to be high on conventional tray with total water use of 200m^3 while a significant saving was observed on SRI-tray with only 18 m^3 of water.
Biology & agriculture	Relationships observed between Trichoderma inoculation and characteristics of rice grown under system of rice intensification (SRI) vs. conventional methods of cultivation.	Doni e*t al*.	2016	Results showed that the presence of Trichoderma asperellum SL2 associated with SRI cultural practices led to significant increase in rice seedling growth, germination rate, vigour index and chlorophyll content as well as elicited more favourable phenotypical responses from given genotype potential. The study observations further illustrated that for some parameters, there were no significant differences between inoculated and uninoculated SRI plants, both giving results superior to those for conventionally-grown plants even when inoculated. This indicated that SRI growing conditions are more favourable for Trichoderma to contribute towards the growth, physiological traits, nutrient uptake and yield of plants, whereas conventional management methods diminished or inhibited these effects.
Economy & agroecology	Transforming the economy of small scale rice farmers in Malaysia via the system of rice intensification (SRI).	Doni *et al*.	2016	This study, which was based on field trials by farmers, showed that SRI can give satisfactory results and high economic productivity. Hence, it was concluded that SRI method can be used by small farmers to fulfil their family's rice needs and contribute to the nation's food security.

2.5 Modelling Soil & Water Nutrients Changes

As more interest in land use management especially for soil and water quality problems is increasing, methods for quantifying the effects through watershed modelling are needed (Jung *et al.,* 2014). Thus, a model-based study is required to obtain information on the effects of SRI. Among all the models applicable, soil and water assessment tool (SWAT) developed by the United States Department of Agriculture (USDA) is used to simulate water and soil nutrient transport for the paddy field.

2.5.1 Soil and Water Assessment Tool (SWAT)

SWAT (Arnold *et al.,* 2012) is a basin scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields in ungauged watershed. The model is physically based on computationally efficient and capable of continuous simulation over a long time period. The SWAT model is an advancement of the simulator for water resources in rural basins (SWRRB) and routing outputs to outlet (ROTO) models. The SWAT model development was influenced by other models like CREAMS (Knisel, 1980), GLEAMS (Leonard *et al.,* 1987), and EPIC (Williams *et al.,* 1984). Figure 2.6 depicts the summary on a standard SWAT model process for watershed simulation.

Gassman *et al.* (2007) have indicated that a key strength of SWAT is a flexible framework allowing the simulation various structural and non-structural best management practices such as conservation tillage, cover crops, application rate and timing of fertiliser, nutrient management, buffer strips, flood prevention structures, grass water ways as well as parallel terraces. One of the salient aspects about SWAT is that it makes use of much readily available data as possible and enables the making of reasonable assumptions when data is not available (Grassman *et al*., 2007). There is a large crop database with relevant crop growth parameters for more than 100 crops including paddy readily available for simulation. The model allows the values for these variables to be put from the records of observed data or generated during the simulation from long-term records available only at several stations (Grassman *et al*., 2007).

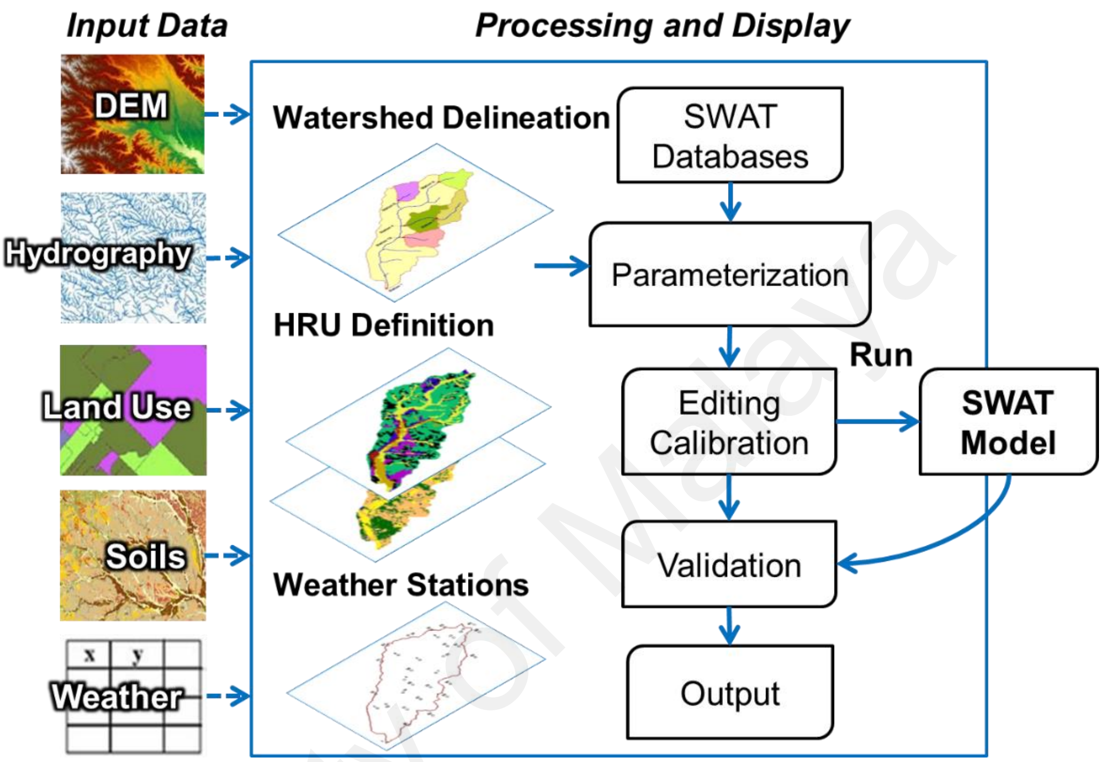


Figure 2.6: Watershed simulation process with the SWAT model

2.5.2 SWAT & Agriculture Watershed Modelling

SWAT model has been proven effective for assessing water resource and nonpoint-source pollution problems for a wide range of scales and environmental condition worldwide (Gassman *et al*., 2007). Although SWAT is generally applied to larger river basin, many studies have used it to simulate annual water and sediment yield as well as water quality at both river basin and small watershed scale (Kang *et al*., 2006; Lam *et al.*, 2011). For lowland areas located in the north of Peninsular Malaysia, no previous study has been published using the SWAT model to evaluate environment improvement in organic rice paddy plantation at the watershed level.

A study on adapting paddy field into SWAT model was done by Sakaguchi *et al.* (2014). Water balance in the irrigated paddy fields was reasonably modelled by the modified SWAT with the developed paddy module and this modified SWAT is effective for watershed-scale modelling for watershed containing paddy fields (Sakaguchi *et al.,* 2014).

Kang *et al.* (2006) have applied SWAT to develop total maximum daily load (TMDL) programmes for small watershed containing rice paddy fields, which utilised the integration of SWAT, geographic information system (GIS) and remote sensing (RS) to simulate the water balance and water quality from irrigated paddy fields. Calibration and validation of parameters related to hydrology and water quality were carried out by comparing model predictions with the field data collection of 4 years. As a result, the simulate runoff and water quality values were considered acceptable, which was close to the observed data.

Jung *et al.* (2014) evaluated SRI water management using integration of SWAT and APEX programme in an agriculture watershed. The results showed that water could be saved with nutrient load reduced by just applying SRI water management for rice paddies. Dechmi and Skhiri (2013) applied SWAT model to evaluate the best management practices (BMP) under intensive irrigation by evaluating four BMP scenarios (nutrient management, irrigation management, tillage operations and combines BMPs) on their level of total suspended sediment (TSS), organic P, soluble P and total P. Additionally, Lam *et al*. (2011) have applied SWAT to record the impact of agricultural best management practices on water quality in a North German lowland catchment.

CHAPTER 3: MATERIALS AND METHODS

This chapter discusses the methodology used to achieve the objectives as stated in Chapter 1. This study was divided into three major phases to be in line with the three objectives previously mentioned. The first phase was the preparation of experimental plots and the assessment of soil and impounded water quality. Second phase of methodology focuses on quantifying the relationship between parameters and comparison studies. Lastly, this chapter presents the use of SWAT modelling approach.

3.1 Characterisation of Soil and Impounded Water Quality

3.1.1 Description of the Marginal Land

(a) ***Geographical location***

The field experiment for system of rice intensification (SRI) on marginal land was carried out on a research farm. The study site is located in the eastern part of Kedah district of Sik and is bordered by Padang Terap district to the north-west, Thailand to the north, Baling district to the south, Kuala Muda district to the south-west, and Pendang district to the west. The study site (06^{o}02.964 N, 100^{o}50.410 E) comprises paddy plots, various vegetable plots, fish pond, chalets and compost hut on 4 hectares of land. It is characterised by its hilly relief with steep slopes of about 66.19%.

(b) ***Climate and Weather***

Figure 3.1 below shows the average temperature and rainfall pattern for the past 25 years in Kedah. It is usually dry and warm from January to April with highest average temperature of 27.31°C and wet season from August to December where August received the highest average rainfall 325.9 mm. Humidity is consistently high, averaging between 82% - 86% per annum.

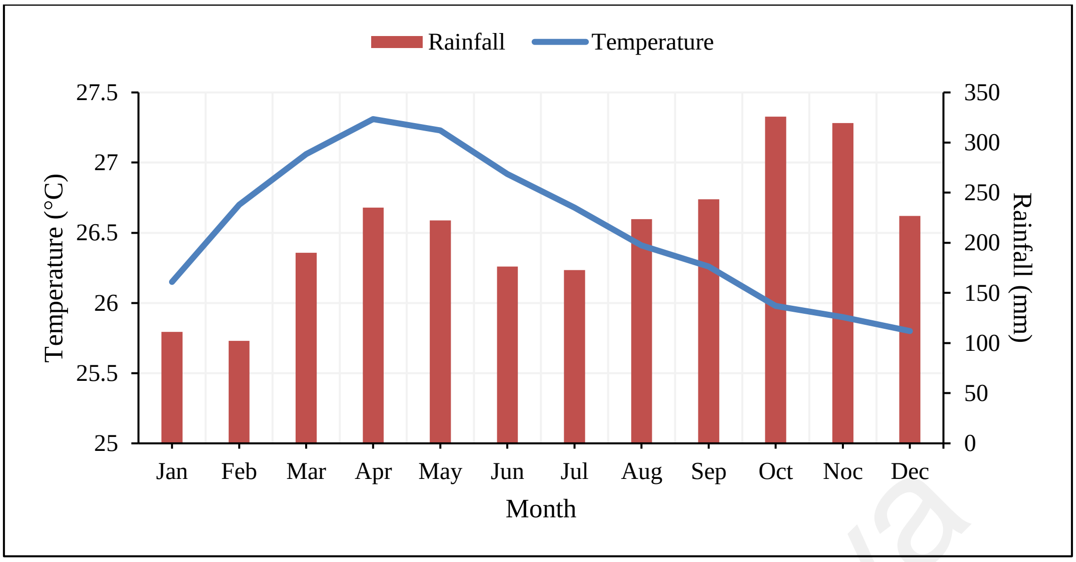


Figure 3.1: Average monthly temperature and rainfall for Kedah (1991-2015) (Country Historical Climate - Malaysia, 2017)

(c) *Cropping history*

More than three decades ago, the study site was a paddy field. It was the source of income to most villagers in Kampung Belantik. However, paddy cultivation activities have been stopped due to various obstacles including no good farming infrastructure, lack of agriculture assistance and capital. According to an interview session with Tuan Haji Marzuki, the project leader at the study site, there is no proper documentation on historical cropping information at Kampung Belantik prior the establishment of the paddy farm in 2010 (personal communication, March 14, 2014). Therefore, the Belantik Agro Cooperative has stepped in and gave initiative to develop the area as an organic paddy farm. Over there, the farmers planted their paddy by implementing the system of rice intensification (SRI).

(d) *Soil characteristic of marginal land*

Soil at the research area is classified as Rengam series (deep coarse sandy clay soil derived from granite). Due to the establishment of study area, it was found that the land was bulldozed, thus exposing the subsoils. Soil at the study site was reportedly unsuitable for farming production as it is categorised as sandy-clay soil with no topsoil, low pH (5.26

– 5.80) and low CEC (< 3 meq/100g soil) due to being low in organic matter in subsoils. This soil characteristic created problems for growing crops; the sandy soils have a high leaching capacity while the clayey soils have a very low infiltration rate. This has therefore reduced the leaching, but resulted in problems with nutrient loss through soil erosion. If not properly managed, the use of these soils will cause problems to the environment such as the pollution of river system due to soil erosion and the leaching of nutrients.

3.1.2 Experimental Design

3.1.2.1 Experimental Plots Preparation

Twelve experimental paddy plots were prepared on four hectares of land located in Kampung Belantik, Kedah (06°02.964 N, 100°50.410 E). Map area of the study site is shown in Figure 3.2.

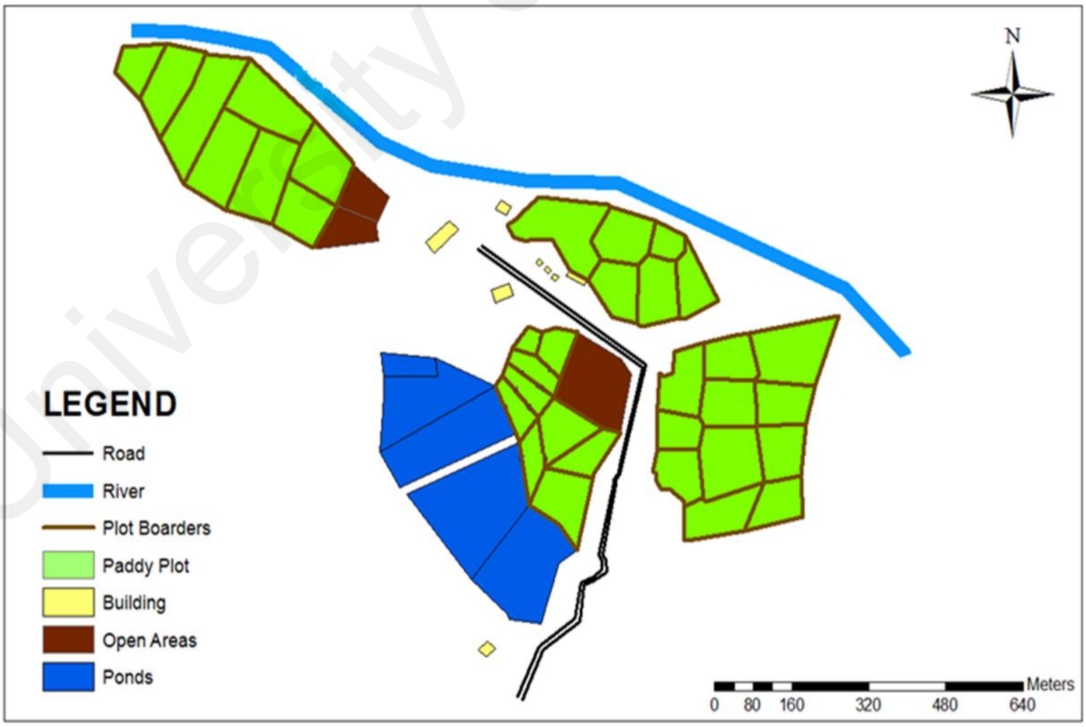


Figure 3.2: Map area of study site

The study site is located next to the Lintang River with more than 20 paddy plots, but only 12 plots are in use during the experimental period. Field visit to the study site was carried out for six months from January to July 2014 for observing site and collecting data for soil and water samples. During the observation from field visit, process flow for paddy plot preparations at the study site until transplanting stage are summarised in Figure 3.3.

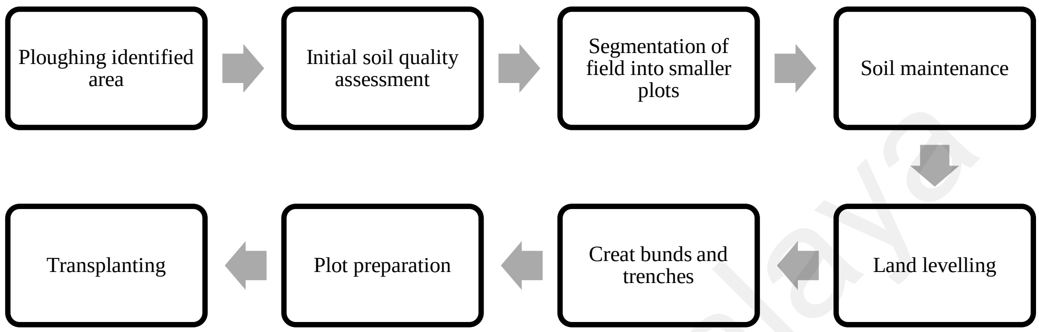


Figure 3.3: Process flow of experimental plots preparation

(a) ***Ploughing***

Ploughing was the first step carried out for land preparation for the experimental plots. Due to the structure of coarse soil, a tractor was used to dig up, mix and overturn the soil as well as removing weeds. The whole surface was then remained covered with water of about 20-30 cm deep.

(b) ***Soil properties of the site***

Before paddy was transplanted at the experimental plots, a kilogram of soil samples was taken randomly at 40 cm depth from the soil surface using Dutch Auger and analysed at Physical Soil Laboratory in Malaysia Agricultural Research Development Institute (MARDI), Serdang. At the laboratory, the soil physical properties and initial soil quality status were assessed. An initial soil quality assessment is crucial in this study as these results were used in the comparison study (Sub-chapter 3.4). The initial result of soil physical properties is presented in Table 3.1.

Table 3.1: Physical properties of soil in experimental plots before SRI

Parameters	Value
Physical properties	
a) Sand (%)	47.4
b) Silt (%)	10.8
c) Clay (%)	41.8
d) Bulk density	1.15
Textural class	Sandy clay

(c) *Segmentation field into smaller plots*

The ready fields were then divided into smaller plots. Twelve smaller plots were segmented as shown in Figure 3.4. The average size of each plot was 0.5 to 1 acre each.

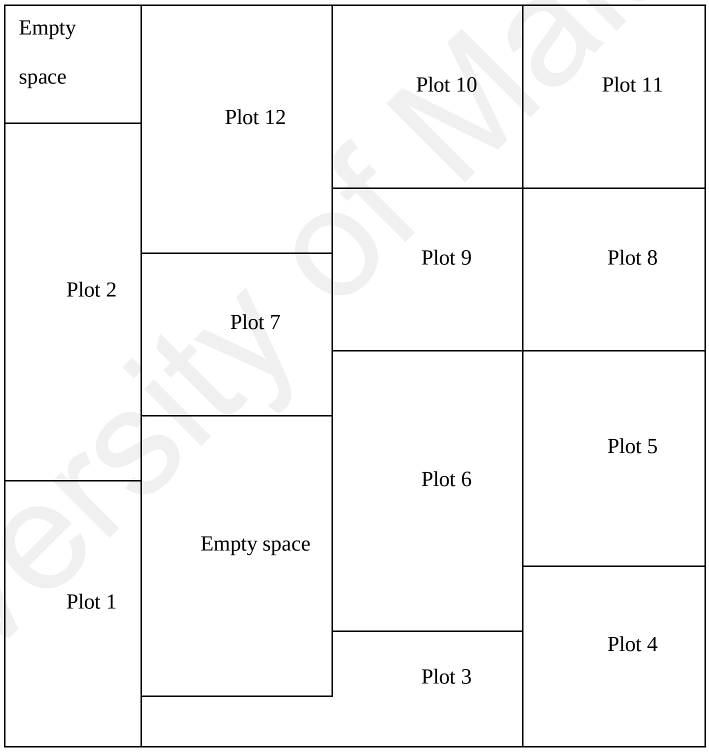


Figure 3.4: Location of plot for the experimentation of SRI (drawing is not up to scale)

(d) *Soil maintenance*

The objective of organic matter application in the paddy plots is to repair the soils. Application of organic matter is very useful especially in sandy soils to help increasing water and nutrient retention in the soils and feeding soil microbes. At the study site, organic fertilisers and compost were self-made by the farmers. The main component of fertiliser is Local Micro-organism (MOL), which can also be used as an activator for preparing the compost. The MOL was mixed with water and sprayed directly to the soil for fertilising the soil and increasing nutrients.

Farmers at study site also used tender bamboo shoots or base of the banana tree stump as the main fertiliser materials. These materials then were crushed and mixed with sugar. Following this, the materials were soaked with water for up to 14 days. Finally, one litre of the fertiliser was added to 10 litre of water. This similar method was used to produce other types of fertiliser by mixing animal dung with paddy straw and tree leaves, which were left to soak for 14 days.

(e) *Land levelling*

A hoe and wooden plank were used to make the field flat (no dips or mounds) and horizontal (no slope). A properly levelled field allows for more even water distribution, needs less water to fill up, reduces weed growth and helps in achieving uniform crop maturity (Bautista, 2016).

(f) *Bunding and trench*

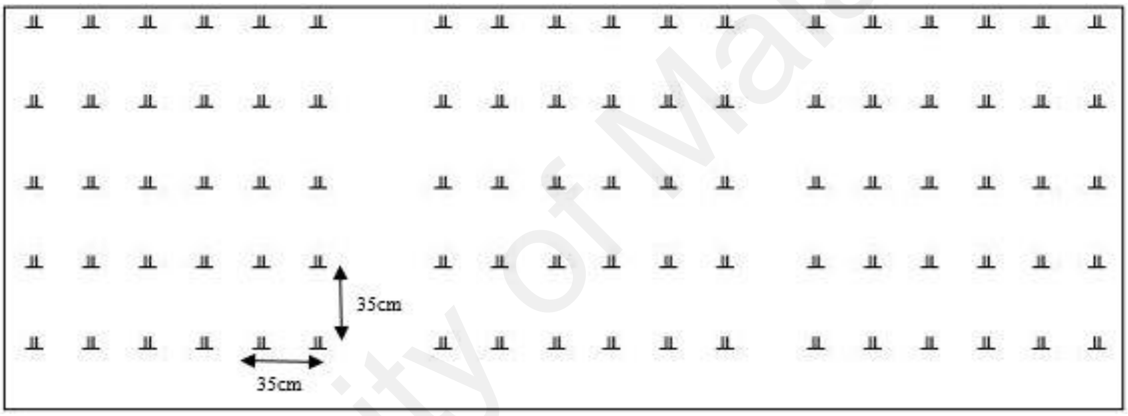
Bunds and trenches were built at the parameter of every plot while the land is still wet using a hoe. Bunds constructed were well compacted and appropriately sealed with no cracks as creating bunds will minimise water loss through seepage (particularly in sloping lands). The distance of bunds is 30 cm from the trench. The trench is essential to provide and control irrigation water coming in and out of the experimental plots.

(g) *Plot preparation*

When the experimental plots are ready, horizontal grid lines were marked on the soil. This process was done using a long stick, ropes and measurement tape. These lines were used as point indicators for the farmers to transplant the young paddy seedlings during transplanting stage. The spacing measurement between each point was 35 cm x 35 cm.

(h) *Transplanting*

The young seedlings aged between 8 to 15 days were sown in the experimental plots according to the ratio of 5 or 6: 1. Meaning that, in every horizontal row, there are only 5 to 6 seedlings sown. The distance between the next transplanting points was twice from the previously sowed seedling point. Figure 3.5 shows the transplanting concept used in the experimental plots.



* Transplanting points with ratio 6:1 with 35 cm x 35 cm spacing

Figure 3.5: Seedling transplanting concept in experimental plots

Figure 3.6: Farmers transplant young seedlings on to the well-prepared paddy plot

3.1.2.2 Water Application and Plot Maintenance

During the vegetative period, irrigating and maintaining the soil nutrients are among the crucial stages in paddy cultivation. Water helps the crops to efficiently use soil nutrients, aids in weed control, influences farm operations, dissolves soil nutrients, controls temperature as well as facilitates field operations and soil biological processes. Water application into the plots, types of fertilisers and its application ratio were carefully controlled and monitored.

(a) ***Water irrigation management***

The source of water for paddy cultivation into the paddy plots is from Lintang River, which is located next to the study site. Due to lack of irrigation infrastructure, water gate was built at the river to supply water to the paddy plots. The irrigation infrastructure was built using 1.5 km long polyvinyl chloride (PVC) pipe buried underground. The farmers manually controlled the amount of water supply needed to the experimental plots. Schedule for the water circulation management is displayed in Table 3.2 below:

Table 3.2: Water management schedule in experimental plots

Days after transplanting (DAT)	Depth of water (cm)	Plot activity
0-10	1-2	Water only in trench
10	15-20	Plough, weeding & fertilisation
11-18	Dry	Water only in trench
19-20	15-20	Plough, weeding & fertilisation
21-28	Dry	Water only in trench
29-30	15-20	Plough, weeding & fertilisation
31-38	Dry	Water only in trench
39-40	15-20	Plough, weeding & fertilisation
41-49	Dry	Water only in trench
50-70	1-2	Fertilisation
96-105	Dry	Water only in trench
105	Dry	Harvesting

During the crop establishment on early days after transplanting (DAT), water depth was maintained at 1-2 cm and drained several weeks before harvesting. At the vegetative stages when fertilisation and soil maintenance activities were active, the experimental plots were flooded with 15 - 20 cm depth of water for several days and then drained. This system is critical to ensure that the plots would not be continuously impounded with water and that farmers can easily control the plot to be drained when necessary. Meanwhile, the main purpose for flooding paddy plots with controlled drainage is for weed control (Sahid & Hossain, 1995).

At the study site, a systematic schedule for farming activities, types and amounts of fertiliser used were followed by the farmer to prevent pest infection. This process is crucial for balanced paddy growth and to make sure that all crops will have sufficient nutrient supply. In the experimental plots, soils were enhanced using mostly organic fertilisers with a ratio range of N:P:K 3-3-3 to 6-6-6. These were applied during the early stages until the vegetative stage of paddy cultivation. Enriched organic fertiliser with a ratio range of N:P:K 6-4-14 was used towards the mature stage of paddy. Meanwhile, organic insect repellent was used to prevent pest infection. Summary on organic fertiliser material application and its quantity are presented in Table 3.3.

Table 3.3: Summary on farming activities and fertiliser use in experimental plots

Age of paddy (days)	Activity	Material used	Quantity (kg)/ acre
-2 day before transplanting	Land preparation	Bio Organic fertiliser (dust) N:P:K 3-3-3	2,000
		Nutrient uptake efficiency (NUE)	0.4
0	Transplanting		
10 DAT	Soil aeration	Compost	
	Pest control	Organic insect repellent	
15 DAT	Fertilisation	Organic granules fertiliser, N:P:K 6-6-6	175
20 - 25 DAT	Pest control	Organic insect repellent	
	Fertilisation	Bio-organic fertiliser (dust), N:P:K 6-6-6	175
30 - 35 DAT	Fertilisation	Organic granules fertiliser, N:P:K 6-6-6	175
	Soil aeration	Compost	
40 - 50 DAT	Fertilisation	Foliar organic fertiliser	
	Soil aeration	Compost	
50 - 55 DAT	Fertilisation	Granules fertiliser, N:P:K 6-4-14	175
	Pest control	Organic insect repellent	
60 - 65 DAT	Fertilisation	Foliar organic fertiliser	
75 DAT	Fertilisation	Granules fertiliser, N:P:K 6-4-14	175
105 DAT	Harvest		

3.1.3 Assessment of Soil and Impounded Water Quality

Observation on SRI method process was done from 28th January 2014 until July 2014 at the experimental plots. Five main farming stages have been identified, which are land preparation (LP), transplanting (TP), water circulation (WC), fertiliser management (FM) and harvesting (HV). Samples were collected at different farming stages since every stage has different farming activities conducted such as sowing seedlings, weeding and soil aeration that will affect the different level of nutrients available for soil and impounded water quality. Descriptions on the five main farming stages are explained in Table 3.4. Paddy soils and impounded water samples were collected for each stage mentioned above.

Table 3.4: Description on farming stages

Farming stages	Description
Land Preparation (LP)	The land preparation process was conducted before a new farming cycle starts. The process took up to 30 days for the soils to be ready. The soil moisture was enhanced by levelling, bunding and organic matter application. The weeds were cleared, and the field was ploughed by tractors to a certain depth. Manures and fertilisers were added to the soil. The whole surface then remained covered with water.
Transplanting (TP)	Paddy seedlings were first prepared in a nursery followed by transplanting that was done on the field. In SRI, transplanting is recommended to be at an early age of seedling (at the 2-leaf stage (about 8-15 days after germination). The seedlings were transplanted with only one seedling per hill and wide spacing (35 cm x 35 cm, or more) adopted in a square grid.
Water circulation (WC)	Paddy fields require regular maintenance, such as occasional weeding and thinning out the most crowded patches (soil aeration) using a mechanical weeder. Alternate wetting and drying (AWD) irrigation were applied during the vegetative growth phase to keep the soil in aerobic condition and moist. AWD was done 7-10 days between watering for the soil to dry.
Fertiliser management (FM)	Fertiliser application was actively applied during the vegetative growth where compost and N-fertilisers are applied at tillering stage and after weeding (about 24-30 days after planting and 60 days before harvesting)
Harvesting (HV)	During the maturation stage where the paddies are ready to harvest, paddy fields were left to dry, hence no water samples were taken at this stage.

3.1.3.1 Soil Sampling and Laboratory Analysis

Various nutrient elements in soil are potentially available to crops and the purpose of soil testing is to estimate them as accurately as possible. For determining soil chemical content, 1 kg of soil was collected using Dutch Auger randomly at every paddy plot sampling point (Figure 3.7). For each point, soil samples were collected at two depths within 0 cm-20 cm and 20 cm- 40 cm. This depth was recommended because about 80% of root systems of food crops remain in this soil depth (Fageria & Stone, 2006).

Figure 3.7: Researcher using an auger to pull out soil from identified depth

The samples were then stored in high-density polyethene (HDPE) plastic bags, which were then labelled and stored in a Coleman box at 4°C while transporting it to the chemical lab for analysis. A handful of fresh soil were separated and packed into smaller plastic bags and stored in a freezer. The rest of the soils were then dried at room temperature, pounded with a wooden mortar and sieved through 2 mm sieve size.

Soil chemical analysis was done in the laboratory where soil pH, electrical conductivity (EC), nitrogen (N), organic carbon (OC), phosphorus (P) and cation exchange capacity (CEC) were determined. Soil pH was measured by suspending 10 gram air dried soil in 25ml of water in a bottle with screw cap (Rowell, 1994). The suspension was then shaken and measured with a glass electrode and a digital pH meter. The same procedure was applied for measuring soil EC where another 25 ml of water was added into the suspension. Later, the suspension was measured for EC using an EC meter. N in soil was determined by Kjeldahl digestion, which is a classical procedures digestion method (Jones, 1991) followed by distillation (Figure 3.8). The distillate was analysed by titration with 0.5 HCI concentration.

Figure 3.8: Kjeldahl distillation unit

The determination of soil organic carbon is based on the Walkley-Black chromic acid wet oxidation method (Rowell, 1994). Oxidisable matter in the soil was oxidised by 1 N $K_2Cr_2O_7$ solution. The reaction was assisted by the heat generated when two volumes of H_2SO_4 were mixed with one volume of the dichromate. The remaining dichromate was titrated with ferrous sulphate. The titre was inversely related to the amount of OC present in the soil sample.

As for soil phosphorus, Olsen method for extractable phosphorus was used (Rowell, 1994). One gram scoop of air-dried soil and 20 millilitres of 0.5 molar sodium bicarbonate ($NaHCO_3$) solution were shaken for 30 minutes. The mixture was then filtered through Whatman filter paper and the ortho-phosphate in the filtered extract (Figure 3.9) was determined calorimetrically (at 882 nm in a spectrophotometer) by reacting it with ammonium molybdate using ascorbic acid as the reducing agent. Results were reported as parts per million (ppm) phosphorus (P) in the soil.

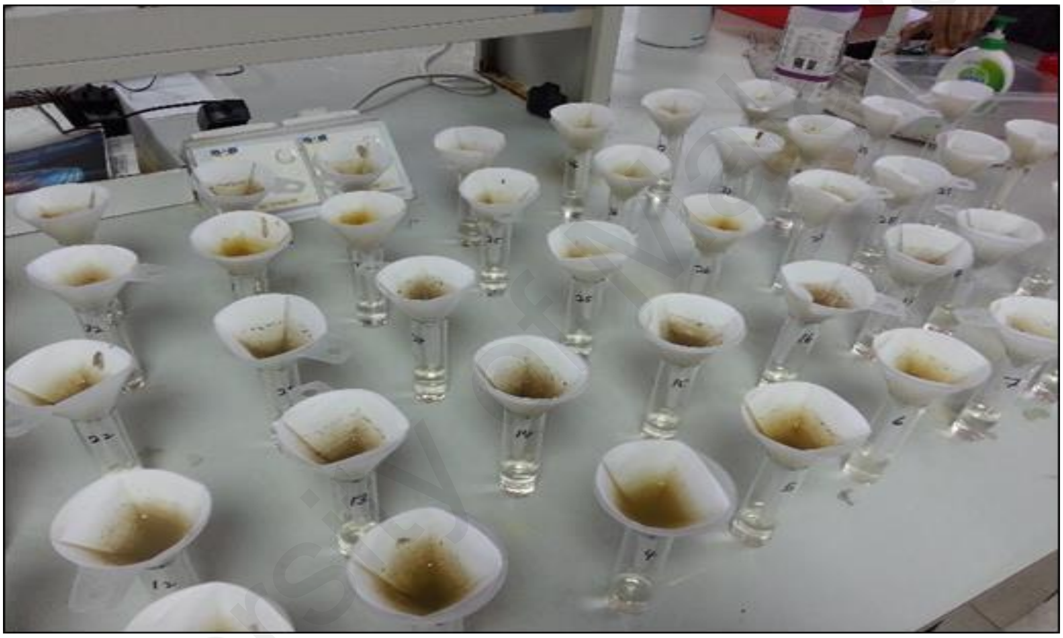


Figure 3.9: Extraction process of soil for phosphorus test

Cation exchange capacity (CEC) values of soil in this study were determined using the pH 7.0 ammonium acetate procedure (Chapman, 1965). The pH 7.0 ammonium acetate CEC method is more time-consuming than effective CEC, but can be readily adapted by most soil testing laboratories. 10g of dried soil samples were soaked with 100 ml ammonium acetate for one night and then left slowly leached (Figure 3.10). The end solution was used to determine the base value for soil. The soil was washed with 95% ethanol to remove excess saturating solution.

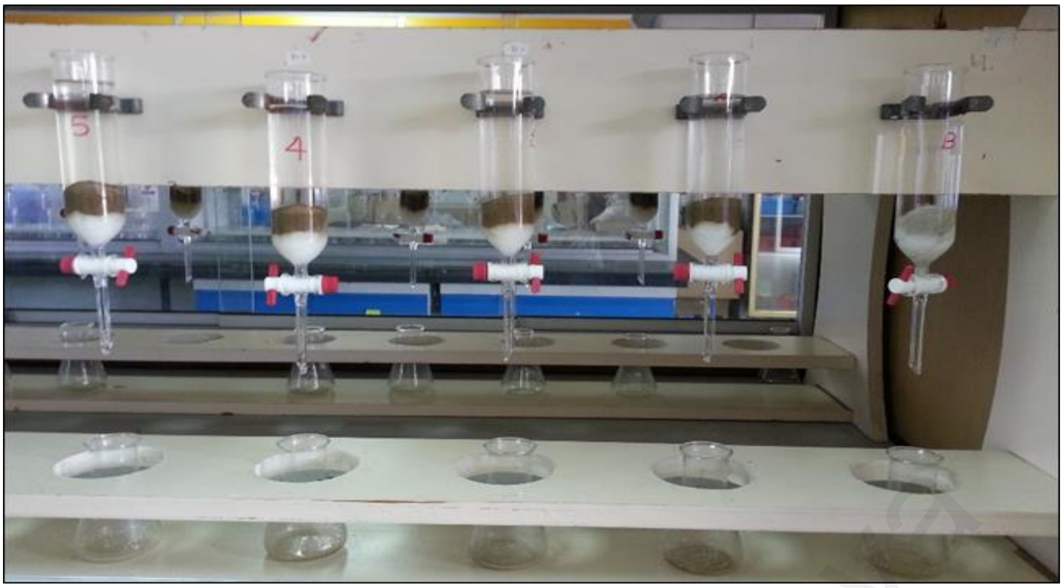


Figure 3.10: Sample of soil leaching process

3.1.3.2 Water Sampling and Laboratory Analysis

Impounded water samples were collected at each paddy plot during every stage of SRI farming stages using high-density polyethene (HDPE) bottles pre-soaked in hydrochloric acid (HCI) for 24 hours and rinsed with deionised water. Global positioning system (GPS) device was used to determine the actual coordinate of the sampling points and to re-confirm the location of the points during subsequent sampling period. The in-situ analysis was done using YSI 6920 V2 logger and Pro-DO meter for pH, electrical conductivity (EC) and dissolve oxygen (DO).

Water samples were analysed in University Malaya chemical lab using water quality test kit for ammoniacal nitrogen (NH_4-N) and phosphate (PO_4). After the samples of each test kit were prepared, a spectrophotometer by Merck (Spectroquant® Pharo 300) was used to read the value of NH_4-N and PO_4 in water samples.

The impounded water quality was analysed based on Standard Methods for Examination of Water and Waste Water (APHA, 2005) for selected parameters. Results obtained were compared with National Water Quality Standards for Malaysia (NWQS), which is a standard set of water quality guidelines used by Malaysia's Department of Environment (DOE) to evaluate the quality status of water bodies in Malaysia. This standard serves as the basic information on the designation of beneficial use classes. Parameter analysed, its units and water quality classes from NWQS are summarised in Table 3.5.

Table 3.5: **N**ational Water Quality Standards for Malaysia (NWQS) (Department of Environment Malaysia, 2011)

Parameters	Units	*Class					
		I	IIA	IIB	III	IV	V
pH	-	6.5-8.5	6-9	6-9	5-9	5-9	-
DO	mg/L	7	5-7	5-7	3-5	<3	<1
EC	µS/cm	1000	1000	-	-	6000	-
NH_4-N	mg/L	0.1	0.3	0.3	0.9	2.7	>2.7
PO_4	mg/L	N.L	0.2	0.2	0.1	-	-

Class I : (Water Supply I) No treatment necessary, (Fishery I) Acceptable for very sensitive aquatic species
Class IIA : (Water Supply II) Conventional treatment required, (Fishery II) Acceptable for sensitive aquatic species
Class IIB : Acceptable for recreational use with body contact
Class III : (Water Supply III) Extensive treatment required, (Fishery III) Acceptable for common and tolerant species. Acceptable for livestock drinking
Class IV : Acceptable for irrigation
Class V : None of the above
N.L : Natural level

3.2 Relationship Establishment between Soil and Impounded Water Quality

3.2.1 Comparative Study of Soil of Marginal Land and Post SRI Farming

Comparative study consists of two parts. Firstly, characteristics of soils under SRI method were compared with initial soil quality data prior the implementation of SRI method. The comparative study was carried out to identify any soil quality improvement at the experimental plots. Secondly, both soil and water quality data from SRI method were compared with conventional paddy farming method. This is important to see whether or not there is any improvement in terms of environmental quality specifically for soil and water.

As there were no conventional approach practices done at the site area, existing data published in research papers on conventional farming were used. Compiling of literature research related to conventional paddy farming specifically on paddy soil and impounded water was done (Appendix K). It is important to emphasise the selection of research paper on paddy farming narrowing it in South East Asia regions. This approach of carefully selecting research papers for secondary data gathering is crucial for the comparison to be significant to this study.

3.2.2 Statistical Analysis

Collected data were subjected to statistical analysis using SPSS 22.0 and spreadsheet of MS Excel. Descriptive statistics in the form of mean, standard deviation, coefficient of variation (CV) and skewness were determined for both water and soil data. The nonparametric Kruskal-Wallis one-way analysis of variance with significant difference at a level $p<0.05$ was used to find significant difference in changes between soil and impounded water quality parameters with SRI farming stages. The Kruskal-Wallis equation is given by:

$$\mathrm{H} = \left[\frac{12}{n(n+1)}\sum_{j=1}^{c}\frac{T_j^2}{n_j}\right] - 3(n+1)$$

Where:

N = sum of sample sizes for all samples,

C= number of samples

T_j = sum of ranks in the j^{th} sample,

N_j = size of the j^{th} sample

The nonparametric method was chosen since it does not require assumptions on normality and homoscedasticity, thereby avoiding any need to transform the data

(Andrews & Carroll, 2001). Post hoc test of pairwise comparison was executed to identify which farming stage give most significant difference for each parameter analysed. Spearman rank-order correlation (Spearman R coefficient) was used to study the relationship between parameters for the non-normal distribution of soil and impounded water quality data. Paired t-test with significant value of $p<0.05$ was employed for comparing between SRI method and before SRI method was implemented as well as its t-test results using mathematical equation of:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where,

$\overline{x_1}$ = Mean of first set of values

$\overline{x_2}$ = Mean of second set of values

S_1 = Standard deviation of first set of values

S_2 = Standard deviation of second set of values

n_1 = Total number of values in first set

n_2 = Total number of values in second set

3.3 Modelling Changes of Soil and Water Quality

Soil and water assessment tool (SWAT) (Arnold *et al.*, 2012) was selected among many other modelling approaches for this study. It is a basin scale and continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, agricultural chemical and yields in ungauged watershed.

The model is physically computationally efficient and capable of continuous simulation over a long time period. Figure 3.11 demonstrates the flowchart process of running SWAT model for Lintang Watershed. Further details and mathematical equations used can be found in ArcSWAT interface for SWAT 2012 user guide (Winchell *et al.,* 2013).

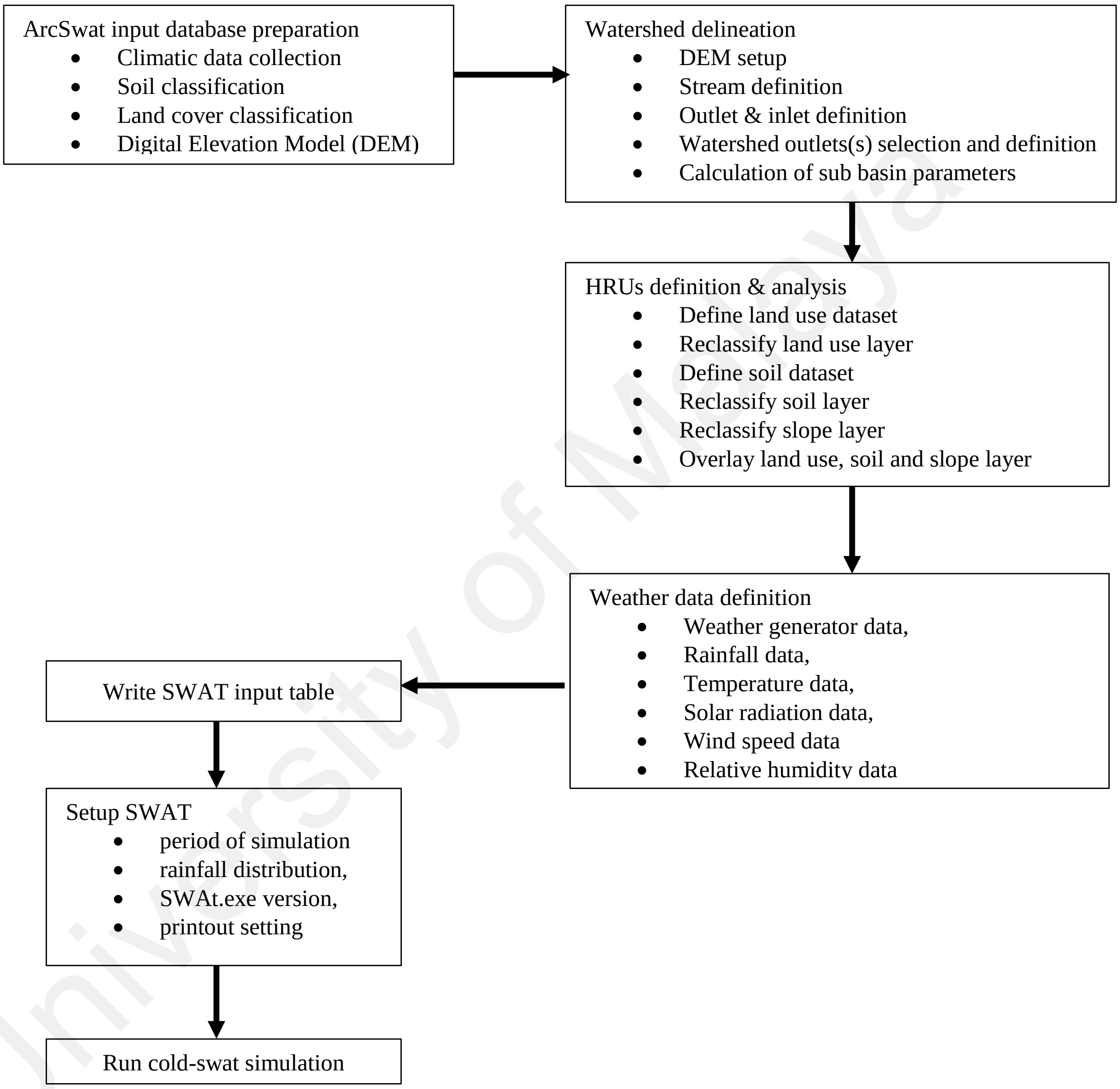


Figure 3.11: SWAT simulation process flowchart for Lintang Watershed

3.3.1 Spatial Data Collection

The tedious and challenging part is collecting the related data that are vital for analysis during the execution of SWAT modelling. To create a SWAT dataset, the interface must access ArcGIS compatible raster (GRIDs) and vector datasets (shapefiles and feature classes) as well as database files, which provide certain types of information on the watershed (Arnold *et al.*, 2012). The necessary spatial datasets and database files were prepared prior running the interface. Types of data collected are displayed in Figure 3.12. All the information were integrated into GIS environment as a SWAT database preparation.

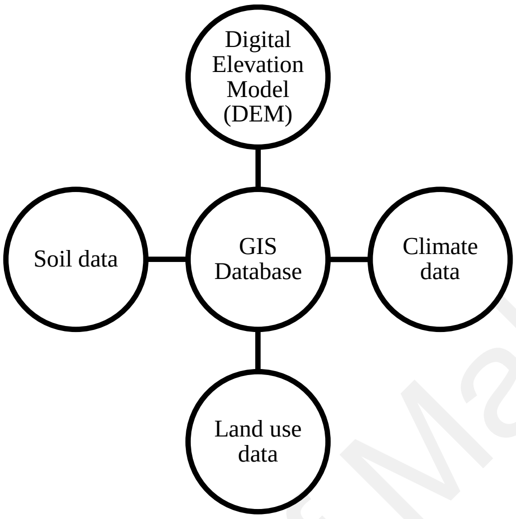


Figure 3.12: Inputs for SWAT model

(a) ***Digital elevation model (DEM)***

DEM map (Appendix C) was derived from contour provided by MARDI, which resulted from combining various sources of agency and projected again using the standard national grid. From the DEM, the highest value of height in Sik, Kedah area was 1,099.98 metre while the lowest value of height was 60 metre. This DEM was used by the interface to delineate sub-basin within the study area (Lintang Watershed) and to estimate parameters such as slope, area, the length of reach, along with the flow path for each hydrological response unit (HRU). Besides, the DEM map was used to delineate associated stream system to the research area.

(b) ***Soil data***

Soil dataset of Lintang Watershed was obtained from MARDI. Soil distribution map and the table list of soil types for Sik, Kedah are presented in Appendix C and Appendix

D. It can be observed that Lintang Watershed consists of two soil types, which are Rengam-Jerangau (8.14 %) and Steepland (91.86 %) (Appendix E). Soil characteristics for Lintang Watershed are shown in Table 3.6.

Table 3.6: Soil characteristics of Lintang Watershed

Soil Name	Soil Texture	Bulk Density	Clay (%)	Silt (%)	Sand (%)	USLE_K
Rengam-Jerangau	Sand-clay	1.15	41.8	10.8	47.4	0.043
Steepland	Clay-loam	1.89	38	38.5	23.4	0.047

(c) ***Land use data***

Land use data input for the district of Sik, Kedah was obtained from MARDI and processed into the SWAT model (Appendix F). Forest was found dominating the land covering the district of Sik with 72.52% followed by rubber plantation with 21.67% of the area (Appendix G). Even though Kedah is known as a rice bowl state for Malaysia, for the district of Sik, paddy farming is not a common activity as it only account for 0.78% of paddy land use from the total area. Low percentage of paddy cultivation area might be due to the topographic structure of Sik, which is mountainous and unsuitable for paddy farming activity. Forest (92.44%) dominated the land covering the Lintang Watershed area followed by rubber plantation (5.81%) and only 1.74% of the area is covered by paddy field (Appendix H).

(d) ***Climatic data collection***

Climatic parameters such as precipitation, maximum and minimum daily temperature, wind speed, humidity and solar radiation data were obtained from Global Weather Data for SWAT website (http://globalweather.tamu.edu/). This website was developed by The National Centre for Environmental Prediction (NCEP) and Climate Forecast System

Reanalysis (CFSR). This dataset is two years in length (2013 until 2014) and was used to simulate the climatic condition at the study area using SWAT model (Appendix I).

3.3.2 Setup and Run SWAT

Once all data were prepared, SWAT model was setup and run. As shown in Figure 3.14, SWAT setup begins from watershed delineation, HRUs definition and analysis, weather data definition, writing SWAT input tables and setup SWAT interface.

(a) *Watershed delineation*

The watershed delineator (Figure 3.13) menu contains all the commands required to perform sub basin delineation and evaluate the results. Topography data were used to delineate a watershed into multiple sub watersheds and to calculate watershed/sub watersheds parameters including slope and slope length. The dialog box was divided into five sections known as the DEM setup, stream definition, outlet and inlet definition, watershed outlets(s) selection and definition as well as calculation of sub basin parameters.

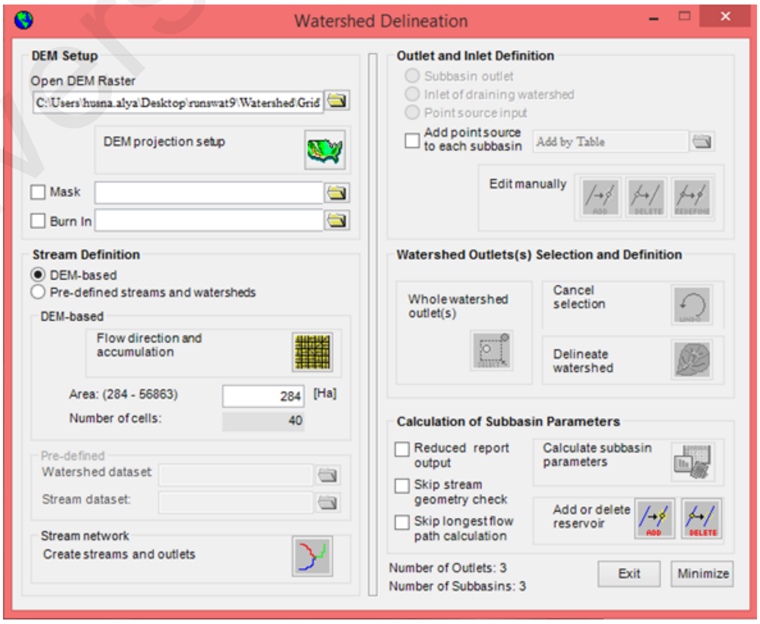


Figure 3.13: Watershed delineation dialog box

(b) *HRU definition & analysis*

Land use, soil and slope characterisation for a watershed was performed using commands in the HRU definition dialog box (Figure 3.14). These tools allow the land use and soil layers load into the current project, evaluate slope characteristics and determine the land use/soil/slope class combinations and distributions for the delineated watershed(s) and each respective sub watershed (Arnold *et al.*, 2012). Once the overlay was finished, a detailed report was added to the current project. This report describes the land use, soil and slope class distribution within the watershed and each sub-watershed unit (subbasin).

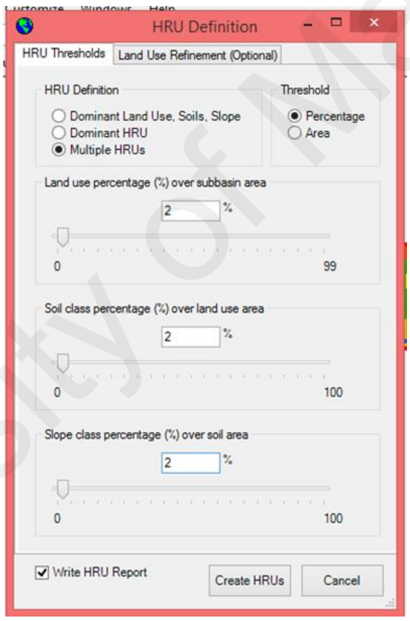


Figure 3.14: HRU definition dialog box

(c) *Weather data definition*

Once the HRU distribution was defined, weather data used in the watershed simulation were imported. Location of weather station was loaded into the current project and assigned weather data to the sub-watersheds. The weather data definition dialog box (Figure 3.15) was divided into six tabs; weather generator data, rainfall data, temperature data, solar radiation data, wind speed data and relative humidity data.

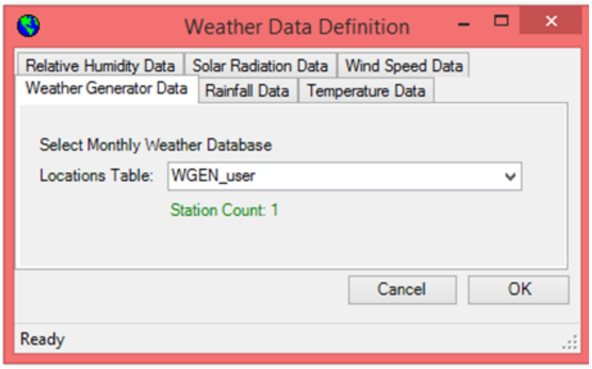


Figure 3.15: Weather data definition dialog box

(d) ***Write SWAT input tables***

Database files containing the information needed to generate fault input for SWAT were built in Write SWAT database tables (Figure 3.16) process. This process can only be done after weather data is successfully loaded.

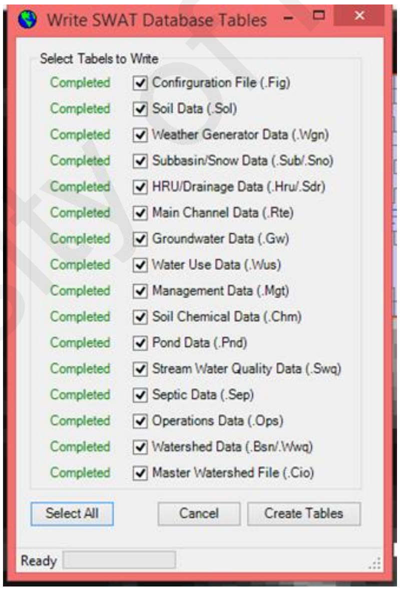


Figure 3.16: Write SWAT database tables dialog box

After all database tables were written, the interface showed the status of all tables written in the database in green completed label next to the SWAT table name indicating that the table was successfully written (Figure 3.16).

(e) *Run SWAT*

Figure 3.17 displays the setup and run SWAT simulation dialog box. To run SWAT model, the period of simulation for rainfall distribution was defined before simulation. The start and end day of the simulation were set based on the first and last days of measured weather data. In this case, the simulation was set starting from 1st January 2013 and ended on 31st December 2014. Rainfall distribution and SWAT.exe version were set to default. For printout setting, the monthly button was selected and number of year skip (NYSKIP) was defined to 1. All desired outputs from the simulation to be printed out were selected before the setup SWAT run was selected. When setup SWAT run was successfully defined, the Run SWAT button was selected.

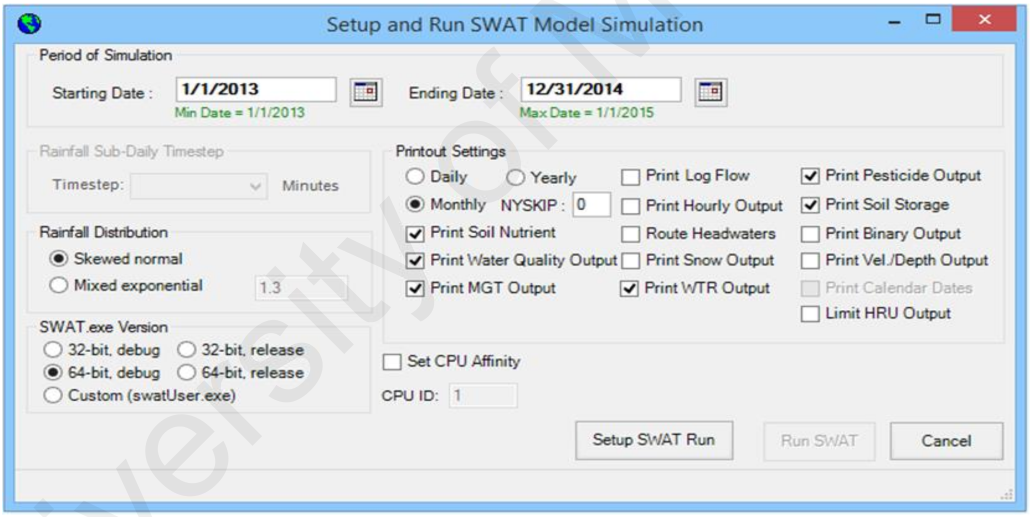


Figure 3.17: Setup and run SWAT simulation dialog box

3.3.3 Analytical Procedure

Outputs of SWAT simulation were plotted by importing the data into an Excel sheet. An Excel filter was used to select the reach, sub-basin and HRU, respectively, and then Excel graphing facilities were chosen to draw graphs. Although this is a relatively tedious process, the use of methods in this study to manually select and to plot graphs using Excel can be adequate. This simulated data was then compared with observed soil and water results from experimental plots.

CHAPTER 4: RESULTS AND DISCUSSION

Chapter 4 starts with a presentation of quality assessment results for soil and impounded water quality. Initial soil quality results before SRI implementation were presented followed by the trend graphs for soil and impounded water quality assessment under SRI method. All parameters were analysed during five farming stages, which are land preparation (LP), transplanting (TP), water circulation (WC), fertiliser management (FM) and harvesting (HV).

Statistical analysis results for comparison studies as well as quantifying relationship and its significant difference are tabulated in Sub-chapter 4.2. Meanwhile, six comparison graphs of selected soil and impounded water quality parameters for preliminary simulated SWAT results with observed data were presented in Sub-chapter 4.3. Lastly, identified limitations for this study are addressed in Sub-chapter 4.4.

4.1 Assessment of Soil and Impounded Water Quality

4.1.1 Assessment of Soil Quality before SRI

An initial study on soil quality at study site was carried out during the early stage prior SRI method implementation. Soil quality parameters analysed in the laboratory include pH, electrical conductivity (EC), cation exchanged capacity (CEC), organic carbon (OC), nitrogen (N) and phosphorus (P). The results were later benchmarked against optimum range of soil quality for paddy based on literature review compilation (Table 4.1). This is because there is no standardised standard on paddy soil quality requirements in Malaysia. However, in a study by Aishah *et al.* (2010), the results were based on the standard range for paddy soil recommended by Malaysia Agriculture Research and Development Institute (MARDI, 2000). According to Dent and Ridgway (1986), EC value of less than 3 mS/cm (< 3,000 µS/cm) is a suitable range for paddy cultivation, while soil should have a high CEC of more than 10 meq+/100 g of soil (Shaidatul Azdawiyah *et al.*, 2014).

Table 4.1: Summary on soil quality optimum range for paddy requirement

Parameters	Units	Range	Reference
pH	-	5.5-6.0	Aisyah et al. 2010
Electrical conductivity (EC)	µS/cm	< 3000	Dent & Ridgway, 1986
Nitrogen (N)	%	0.2-0.3	Aisyah et al. 2010
Organic carbon (OC)	%	2-3	Aisyah et al. 2010
Phosphorus (P)	mg/L	>40	Aisyah et al. 2010
Cation exchange capacity (CEC)	$meq^+/100g$	>10	Shaidatul Azdawiyah et al. 2014

Overall soil quality parameters analysed were relatively low compared to the suggested range for optimum paddy soils (Table 4.1). The finding is presented in Table 4.2.

Table 4.2: Mean results of soil quality parameters prior SRI method implementation

Parameters	Unit	Mean	Standard deviation
pH	-	5.54	±0.05
Electrical conductivity (EC)	µS/cm	6.80	±1.92
Organic carbon (OC)	%	0.43	±0.16
Nitrogen (N)	%	0.06	±0.01
Cation exchange capacity (CEC)	$meq^+/100g$	2.26	±0.53

Mean soil pH value at study site was pH 5.54 ± 0.05, which was higher than the common pH values in other Rengam soil types (pH 4.43 – pH 4.83) in Malaysia. The pH range recorded by Shamshuddin and Fauziah (2010) indicated that Rengam soils are highly acidic. Higher results for pH values may be because of the soil samples that were taken when they were already disturbed due to land preparation process. During land preparation, crop residues from land clearing were left at the identified paddy plot to be naturally decomposed. The organic matter from decomposition process positively influences the buffering capacity of soil, which is the reason soil reaction was stabilised (Fazekašová, 2012), hence rising the soil pH. Mean soil EC was found low (6.80 ± 1.92 µS/cm) indicating the low amount of total salt present in the soil (Dent & Ridgway, 1986).

It was observed that soils at study site were very coarse and hard. The soil here can be characterised as sandy clay soil with the absence of topsoil. As a result, nutrient and organic matter levels were found to be lower in these disturbed sites than in native soils (N = 0.06 ± 0.01 % and OC = 0.43 ± 0.16 %) (Aisyah *et al.*, 2010). Mean CEC values were very low at 2.26 ± 0.53 meq$^+$/100 g of soil. Shamshuddin and Fauziah (2010) mentioned that CEC values for Rengam are commonly low (<10 meq$^+$/100g soil) as Malaysian soils are dominated by kaolinite and sesquioxides (oxides of Fe and Al) in the clay fraction with low negative charge. Low CEC indicated that the soils have a low capacity to retain basic cations such as Ca^{2+}, Mg^{2+} and K^+. These cations are the major nutrients needed in a large amount by crops for their continual growth. Overall, soil quality status before SRI methods was considered low when compared to the suggested optimum soil quality range for paddy soils (Table 4.1). Therefore, a soil improvement is needed before any development on cultivation practices.

4.1.2 Soil Quality Status during SRI Method

Descriptive statistic results for each soil quality parameters of 80 samples are presented in Table 4.3.

Table 4.3: Descriptive statistics of soils quality parameters during SRI method

Parameters	Units	Mean	Standard deviation	Coefficient of variation (%)	Skewness
pH	-	4.83	±0.22	4	0.07
EC	µS/cm	15.45	±4.06	26	1.20
N	%	0.07	±0.03	41	0.84
C	%	0.82	±0.33	40	0.26
P	mg/L	6.62	±2.76	42	-0.01
CEC	meq$^+$/100g	8.41	±1.23	15	0.15

All other soil quality parameters have a coefficient of variation (CV) values greater than 4 % except for pH with the highest being 42% in the case of P, suggesting a greater variation in the soils. This variation of soil nutrients properties might be due to random soil sampling where non-uniform applications of fertiliser were practiced (Fernández & Schaefer, 2012). Other factors can be due to tillage practices, moisture availability or errors in analysis (Swapan *et al.*, 2001). Most of the parameters were positively skewed except for P.

(a) *Soil pH*

The soil in experimental plots during all farming stages was acidic with a mean of pH 4.83 ± 0.21 ranging from pH 4.67 ± 0.21 to pH 4.91 ± 0.21 (Figure 4.1). Soil pH value was discovered sharply dropped from land preparation (LP) to transplanting (TP) stage, but gradually increased afterwards. Overall values for soil pH were shown to be more acidic at sub-soil (depth of 20 - 40 cm) for all farming stages. Moreover, the values of soil pH for both depths were below the optimum recommended value (pH 5.5 – pH 6.0) for paddy farming (Table 4.1).

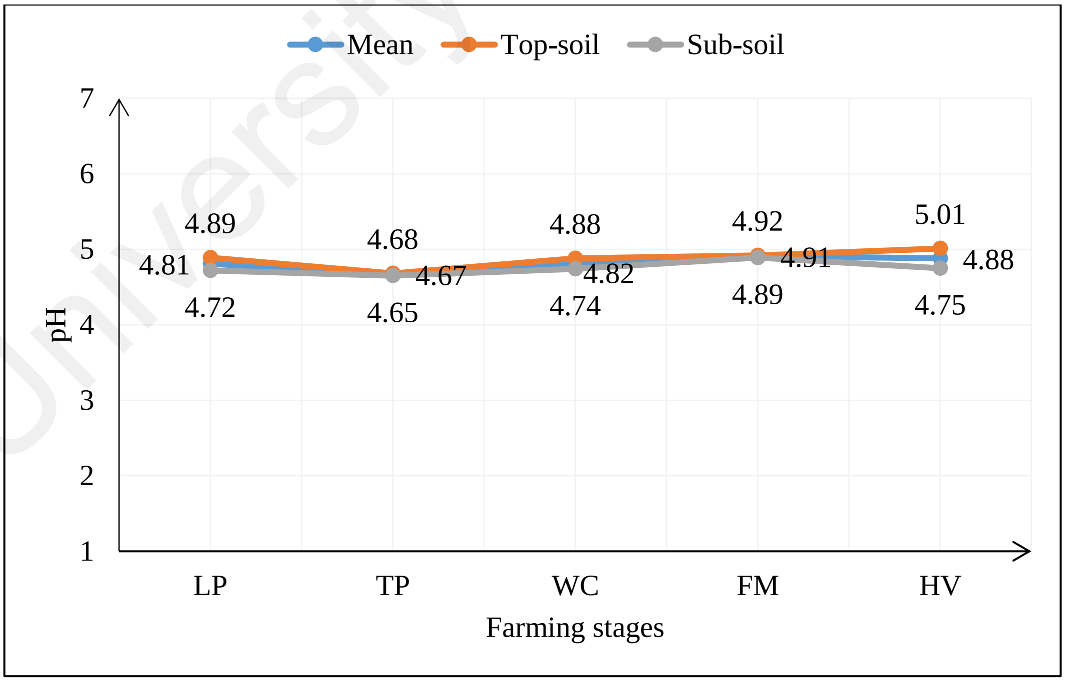


Figure 4.1: Mean pH in top-soil and sub-soil during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

Soil pH is a key property when analysing soil quality (USDA, 2011). The availability of soil nutrients and other chemical compounds in the soil can affect soil pH with the soil pH influencing most (if not all) soil chemical and biological reactions. Optimum soil pH for rice production is between 5.5 - 6.0 (Aishah *et al.,* 2010). The mean soil pH for every stage of farming in this study was found to be lower than the recommended soil pH values for paddy cultivation.

The observed increasing trend of soil pH from TP stage onwards can be explained by the process of flooding the plots where leaching may have occurred. Leaching may result in a slight increase in soil pH due to the lowering of salt concentration (Yadav *et al*.,1988), which can be proved by the decreasing of EC values from water circulation (WC) to harvesting (HV) stages (Figure 4.2). In addition, the application of organic compost increases soil pH (Cogger, 2005), hence increasing the value of soil pH during fertiliser management (FM) stage.

(b) ***Soil electrical conductivity (EC)***

Soil EC is known as the soil salinity indicator. Soil EC values from all farming stages did not show any substantial differences, yet there were variations among the farming stages. Mean of soil EC values ranges from 12.13 ± 0.78 μS/cm to 17.51 ± 4.21 μS/cm with the lowest values detected during HV and highest during WC (Figure 4.2).

EC measures the accumulation of soluble salts in the soil profile. Measurement of soil salts is important as it alters plants osmotic potential and can induce specific ion toxicities or nutrient imbalance. EC values at the early stage of farming started with a relatively high value. However, the EC values have slightly dropped during LP. When impounded water during LP was drained out from the plot to make way for TP stage, soil moisture content was seen at its maximum. At the same time, salt concentration or the osmotic pressure of the soil solution is minimal (Yadav *et al.,* 1988); hence, this explains the low soil EC values during TP stage. Besides, salts concentration in the soil solution reduced as the soil progressively dries out due to evapotranspiration process (Yadav *et al.*, 1988), which reflects the reduction of soil EC values from FM to HV stages.

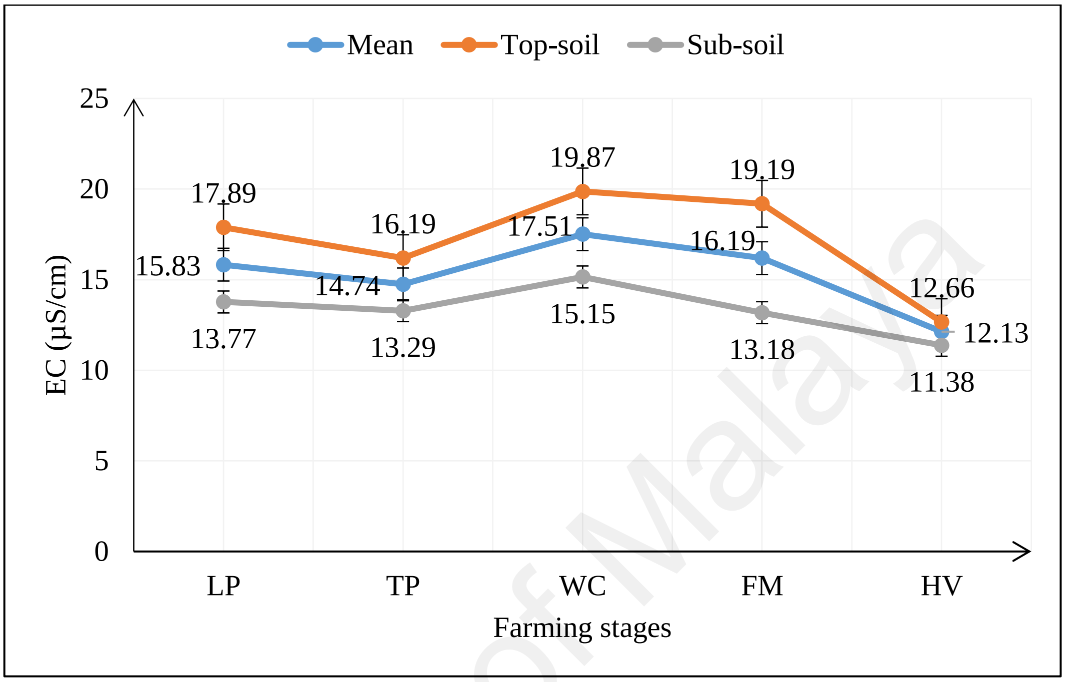


Figure 4.2: Mean electrical conductivity (EC) in top-soil and sub-soil during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

In the depth comparison for soil EC, there were small differences in trend between the two depths, yet the average values of soil EC were higher at the top- soil (0 – 20 cm) compared to sub- soil (20 – 40 cm). At top soil, mean soil EC values were ranged between 12.66 ± 0.43 µS/cm and 19.87 ± 4.04 µS/cm with the highest at WC and lowest values at HV. For subsoil during WC, mean EC values were at their highest with 15.15 ± 2.94 µS/cm and lowest during HV with 11.38 ± 0.45 µS/cm. Nevertheless, average soil EC values in the experimental plots were low, which indicated that the total amount of salt present in the soil was low. The low value of EC will not cause any damage to the crop and is suitable for paddy cultivation (Shaidatul Azdawiyah *et al.*, 2014).

(c) *Soil nitrogen (N)*

Nitrogen analysis measures N in all organic and inorganic forms. Mean concentration values of N fluctuated between 0.05 ± 0.02 % to 0.07 ± 0.03 % (Figure 4.3), which shows that there is significantly low concentration of N throughout all farming stages. The highest concentration of N (0.07%) was found to be present at LP, WC and HV, whereas the lowest concentration was observed at FM (0.05%).

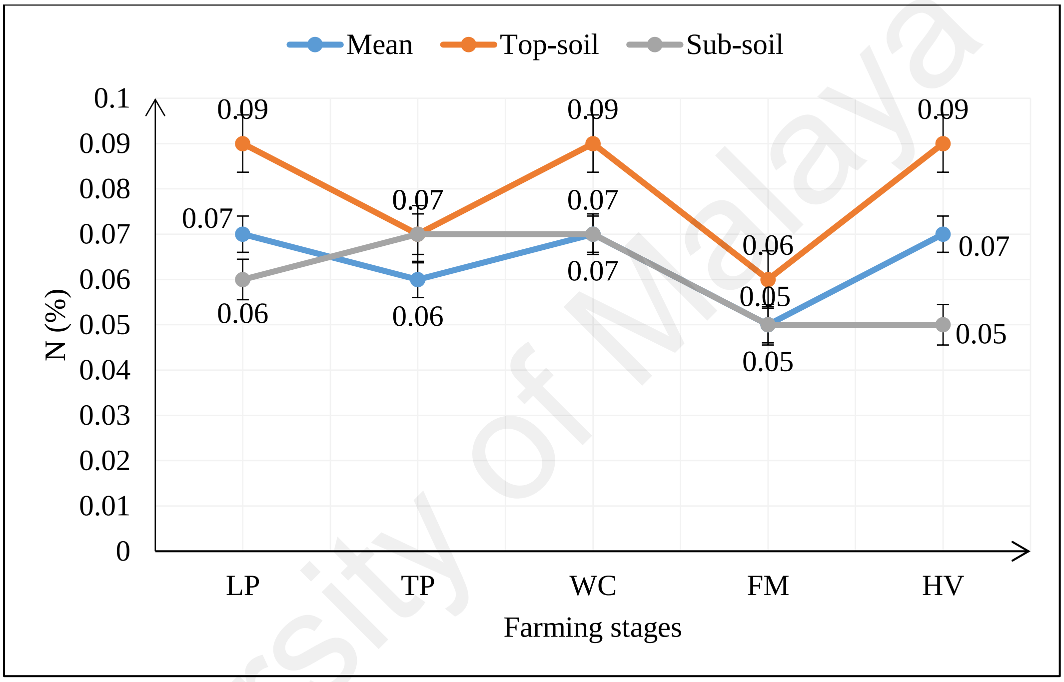


Figure 4.3: Mean nitrogen (N) in top-soil and sub-soil during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

Nitrogen in organic forms is constituted as humus, thus resulting in high accumulation of N during LP and WC stages (Olk, 2008). Decomposition of organic matter and nitrogen mineralisation to moist the soil during LP contributed to the high concentration of N (Olk, 2008). N concentration can be seen slightly reduced as it goes into TP stage. During transplanting, there was an absence of water, and the soil was let in a semi-dry condition with a considerable amount of soil moisture (1-2 cm depth of impounded) (Table 3.2).

During WC stage, most organic insect repellents were applied and the water was supplied to the experimental plots at the same time. Other activities such as soil aeration and weeding were actively in process during WC stage. All of the above mentioned activities contributed to the influence of high concentration of N during WC stage. Ironically during FM, N concentration was low, which may be due to the slow nutrient release of fertilisers. In addition, method of spraying fertilisers may influence the low intake of N at the time of sampling. The concentration of N was high in HV might be resulted from the residues of N that were not taken up by crops.

When two depths of soil were compared for N concentration with the average values for every stage at top-soils (0 - 20 cm) were found higher compared to sub-soil (20 – 40 cm). The figure also shows different trend lines, suggesting there are effects from paddy cultivation activities. A marginal gap of N values between top- soil and sub-soil can be seen during LP, WC and HV. These gaps indicate a higher rate of N loss at the sub-soils compared to TP and FM stages. Water impounding process during LP stage and released of water into plots during WC may explain the high N loss. However, there was no difference in N concentration at both depths during TP (N = 0.07 %). Non-active soil activity and only transplanting of young seedling happened during TP stage may be the reason for the consistent N concentration at both depths.

(d) ***Soil organic carbon (OC)***

Organic matter is a major source of plant nutrient supply through the process of decomposition and mineralisation. Soil organic carbon (OC) showed fluctuates average values throughout the farming stages. Highest mean concentrations were recorded during FM (1.02 ± 0.35 %) with lowest OC recorded during LP (0.63 ± 0.21 %) (Figure 4.4).

Trend lines at both depths for OC slightly differ and OC seemed to be higher at top-soil (0 – 20 cm depth) rather than sub –soil (0 – 20 cm depth). The significant high values at topsoil indicated that there was a large amount or excess of OC accumulation during

FM and HV stages as there was a large gap of OC values between both depths. OC concentration during TP and FM remained the highest at both depths.

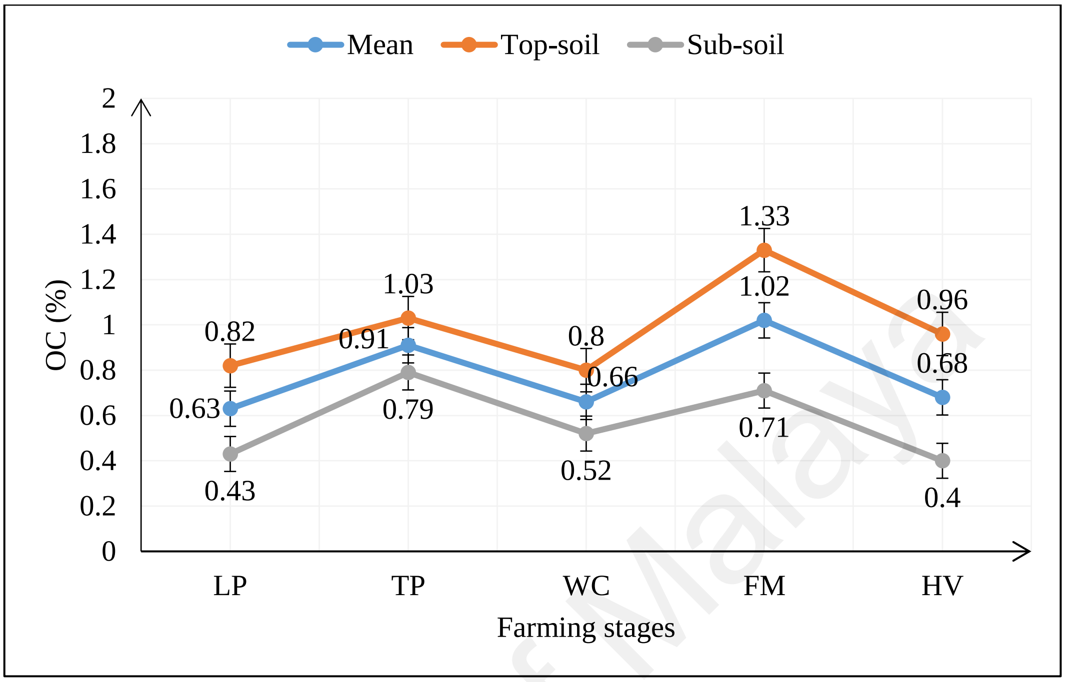


Figure 4.4: Mean organic carbon (OC) in top-soil and sub-soil during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

OC plays a role in developing soil structure, maintaining soil biological health and cation exchange capacity (CEC) as well as maintaining the levels of nutrient mineralisation (Fageria, 2012; Ketterings *et al.*, 2007). The fluctuation trends of OC concentration values may indicate the influence of farming activities.

The high OC concentration at TP stage may resulted from organic content accumulation contributed by humus, which comes from decomposition of crop residues from LP stage (Prescott, 2005; Yadvinder *et al.*, 2005). Meanwhile, high OC during FM may be due to the fresh input of compost during this stage. According to Trost *et al.* (2013), impounded water increases soil moisture and enhances soil microbial activity, causing in an increased decomposition of soil organic matter. The increased microbial decomposition of soil organic matter may lead to lower soil organic content. This explains the low OC content during LP and WC stages. Overall, average OC concentration from early to end stage of farming was below the optimum requirement (2-3 %) of OC for paddy soil (Table 4.1) (Aisyah *et al*., 2010).

(e) *Phosphorus (P)*

Phosphorus is required by plants and present in soils in very much smaller quantities than nitrogen. There was an increase of P concentration throughout the farming stages in the experimental plots with mean values ranging from 1.49 ± 0.54 mg/L to 7.72 ± 3.11 mg/L (Figure 4.5). Overall, the lowest mean P concentration was detected during LP while the highest value was recorded during HV.

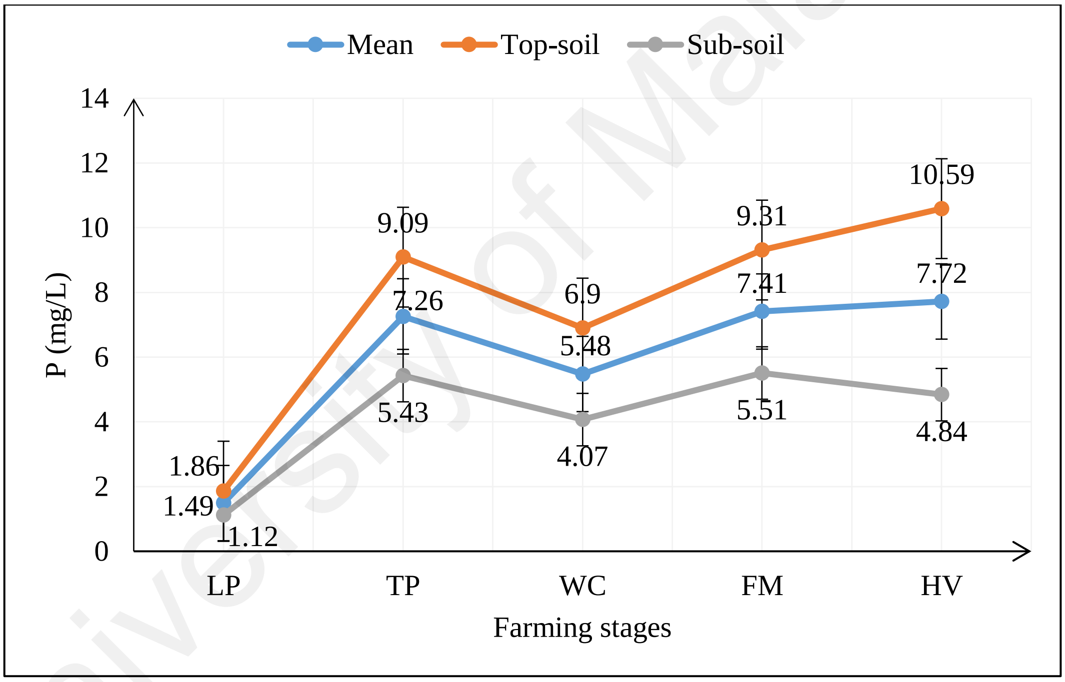


Figure 4.5: Mean phosphorus (P) in top-soil and sub-soil during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

Phosphorus is classified as a primary nutrient since it is essential for growth and often deficient (Young, 1976). However, paddy is a low P-demanding crop (Haifa, 2014). Fluctuated values among the stages may indicate that farming activities influence the P concentration in soils.

Marx *et al.* (1999) explained that P availability in soil decreases during low temperature and wet soil conditions; therefore, this may explain the low P concentration during LP and WC stages. During TP, FM and HV, there were less farming activities happened in terms of soil disturbance at these stages, thus may be the reason of high P concentrations. Apart from that, the source of P coming from fertiliser application during FM stage may also influence the high P concentrations. During HV stage, the value of P was the highest recorded. This shows that there are P residuals that were not taken by the crop. These values need to be considered as the value of P will influence how much fertiliser required to be applied for the next farming cycle.

P concentration was higher at top-soil (0 – 20 cm) compared to sub-soil (20 – 40 cm) and showed substantial gaps between both depths at TP, WC, FM and HV. The large differences of P at these stages indicate the existence of P accumulation at the top-soil. One reason for the abundance of P in soils is the application of fertilisers above plants' requirements; this is due to the perception that P is held by soils and not leached (Leinweber *et al.*, 2002). Thus, there is a high possibility that a large amount of P in soil will be washed away to the nearby water bodies from surface runoff due to rain occurrence as the level of P is high at top-soil during HV stage.

The reduction of P concentration values during LP and WC stages at both depths showed relatively smaller gaps of differences compared to other stages, indicating a higher rate of P leaching. Xaviar *et al.* (1996) explained that impounding plot with water increases the availability of phosphorus where ferric phosphate are reduced to more soluble ferrous phosphates and displacement of phosphate from ferric and aluminium phosphates by organic carbon. Overall, P concentration at the experimental plots (< 7 mg/L) was regarded lower than the recommended soil P for paddy (> 40 mg/L) (Table 4.1).

(f) *Soil cation exchange capacity (CEC)*

Soil CEC value was determined by the amount of clay and humus contained in the soil. Mean soil CEC values were high at LP (9 ± 1.28 meq$^+$/100 g) and FM (9.85 ± 0.56 meq$^+$/100 g) (Figure 4.6). High variance of CEC values was due to the high amounts of organic matter and exchangeable cations (Kogge *et al.*, 2016). High organic matter content in soils is due to slow decomposition rate resulting in the accumulation of large plant residue (Kogge *et al.*, 2016) during LP stage. The rate of organic matter decomposition differs depending on the type of organic material and its turnover (Anderson & Swift, 1983).

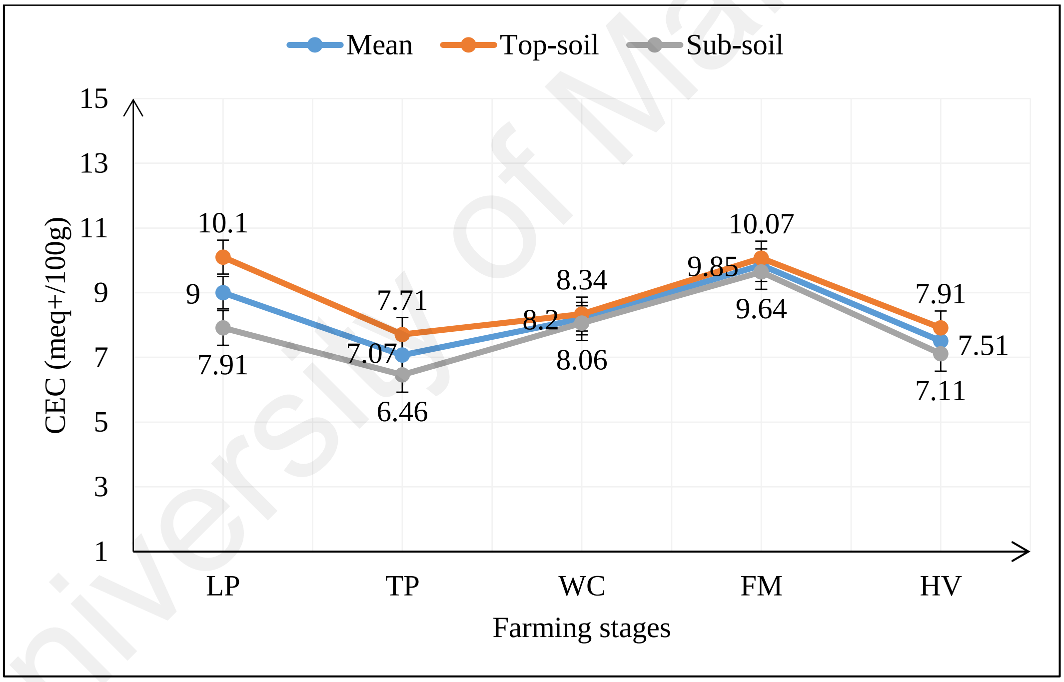


Figure 4.6: Mean cation exchange capacity (CEC) in top-soil and sub-soil during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

The low mean of soil CEC values was recorded at TP (7.07 ± 0.82 meq$^+$/100 g) and there was a sharp decrease in CEC from FM to HV (7.51 ± 0.48 meq$^+$/100 g). Changes of CEC values for both depths showed small significant difference and did not show particular pattern between top-soil (0 – 20 cm) and sub-soil (20 – 40 cm). CEC recorded for the top-soil was from 7.71 ± 0.28 meq^+/100 g to 10.07 ± 0.66 meq^+/100 g and from 6.46 ± 0.64 meq^+/100 g to 9.64 ± 0.36 meq^+/100 g for sub-soil.

CEC is an important soil fertility property as it is often used as a yardstick for judging fertility status (Hartemink, 2006). The presence of clay and humus in soil is important because it acts as a cation reservoir that helps to improve the holding capacity of water and nutrient and reduce the potential for leaching (Murphy, 2015). Soils with high clay and organic matter content have high CEC (Horneck *et al.*, 2011). Hence, this justifies the CEC results shown during LP and FM. High CEC values reflect the higher availability of nutrients to be consumed by plants during both stages.

Meanwhile, during LP and TP stages, there were substantial gaps of CEC measured between top-soil and sub-soil. These gaps can be related to the non-active soil disturbance during LP and TP stages. During LP, samples might have been taken while the experimental plots were left in a still condition after applying nutrient uptake enhancer (NUE) and organic residue to be decomposed. Meanwhile during the TP stage, transplanting of young seedlings does not affect the CEC values at both depths. Despite the moderately high CEC values recorded (> 7 meq^+/100 g), it is still below the recommended CEC values for paddy soils (>10 meq^+/100g) (Table 4.1).

4.1.3 Impounded Water Quality

Descriptive statistic results of each impounded water quality parameter for 37 samples are presented in Table 4.4. All water quality parameters were sampled under four different SRI method stages namely land preparation (LP), transplanting (TP), water circulation (WC) and fertiliser management (FM). Except for pH, all other properties have coefficient of variation values greater than 4% with the highest being 77% in the case of NH_4-N, suggesting that they had a great variation in the impounded water. According to Morales *et al.* (2014), under flooded or during water availability condition in paddy cultivation, ammonium was found to be the main source of N for crop growth. This is because ammonium tends to accumulate with time of flooding process due to lack of oxygen for nitrification. Therefore, this is likely to explain the high variation of NH_4-N.

Table 4.4: Descriptive statistic for impounded water quality in experimental plots

Parameters	Units	Mean	Standard deviation	Coefficient of Variation (%)	Skewness
pH	-	6.59	± 0.27	4	-0.46
EC	μS/cm	59.98	± 9.27	15	0.31
DO	mg/L	7.85	± 2.02	26	1.30
NH_4-N	mg/L	0.96	± 0.73	77	-0.08
PO_4	mg/L	0.33	± 0.14	43	1.87

(a) *Water pH*

Measuring the pH of the impounded water is of a high importance and can actually determine the success or failure of the crop. Mean of impounded water pH values for all stages ranged between pH 6.52 ± 0.28 to pH 6.72 ± 0.15 and consequently considered as weakly acidic (Figure 4.7).

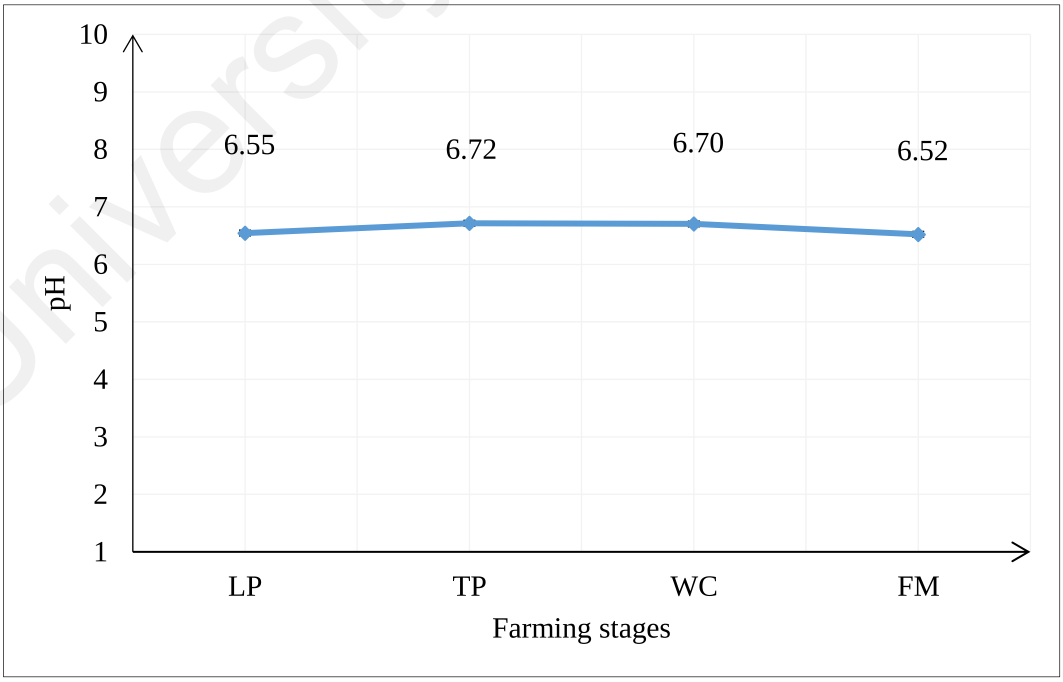


Figure 4.7: Mean pH for impounded water during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

There was a significant change in pH value between all farming changes with high impounded water pH recorded at TP and lowest during FM. The impounded water pH value sharply increased from LP to TP; yet, there was a major drop observed from WC to FM. NWQS proposed the range of pH water quality suitable for irrigation between pH 5 and pH 9 (Table 3.5).

Weak acidic of water recorded was due to the biochemical reactions such as denitrification of nitrogen contained in the irrigation water and dissolution from the application of fertilisers (Stumm & Morgan, 1993). The aerobic condition took place and increased the acidity, hence leading to a decrease in pH. Acidic water can have a damaging effect on plant growth particularly causing nutritional problems, while strongly acidic water (below pH 4) can contribute to soil acidification. However, all the impounded water pH values for all stages were in the permissible range (pH 6.52 – pH 6.72) for agricultural purposes and consequently considered as weakly acidic.

(b) ***Dissolved oxygen (DO)***

Dissolved oxygen (DO) test was chosen because it is the key test for water pollution and also among the main factors affecting aquatic ecosystem in the paddy plots (Halwart & Gupta, 2004). At all sampling points, DO readings measured were below 12 mg/L (Figure 4.8) with recorded temperature ranging between 28^{o}C – 40^{o}C throughout sampling process. Mean of DO gradually increased from LP to TP and sharply increased towards WC. However, a sharp drop of DO was recorded from WC to FM stages.

The mean values of DO were outside the NWQS range for irrigation purpose (<3 mg/L) during TP, WC and FM. Factors such as the raining seasons during sampling may also influence the high concentrations. Oxygen reaction in the water is influenced by the equilibrium reaction between physical, chemical and biochemical of the water (World

Health Organisation, 2011); thus, it causes changes in impounded water temperature and DO.

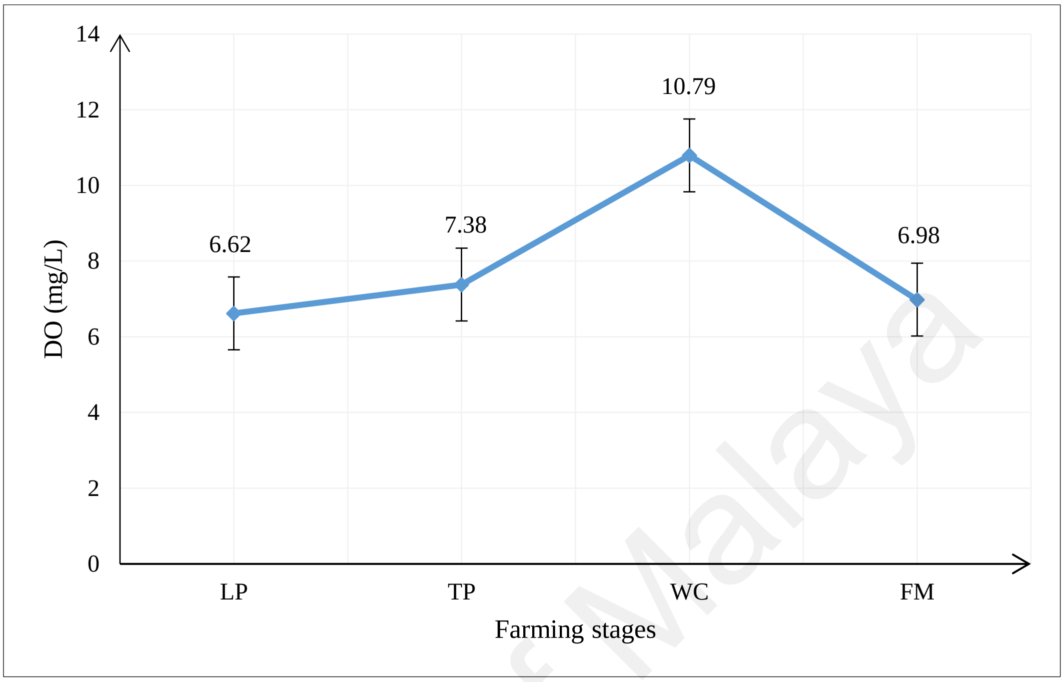


Figure 4.8: Mean dissolved oxygen (DO) for impounded water during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

During WC, water was released into the experimental plots for ploughing and weeding. Hence at this stage, DO recorded the highest concentration values compared to other stages as oxygen compound from water contributed to higher DO level. Low DO concentration values in impounded water indicate less oxygen in water bodies that can be supplied to aquatic life due to a high density of aquatic plants. During LP and FM, organic matters from the previous harvest that were left to be decomposed for land preparation process and high phosphate residuals from fertiliser applications enhanced the blooming of these aquatic plants. During observation at LP stage, abundance of algae plants was found present in the plots, hence justifying the abovementioned situation.

(c) *Electrical conductivity (EC)*

Electrical conductivity (EC) is important for irrigation water as it measures the level of salinity in water (Metcalf & Eddy, 2003). Trends of EC value changes between farming stages have fluctuated, but did not show major differences with EC ranging from 53.28 ± 3.82 µS/cm to 65.84 ± 8.12 µS/cm. High values of EC were shown at LP, WC and FM, while EC values were at their lowest during TP (Figure 4.9).

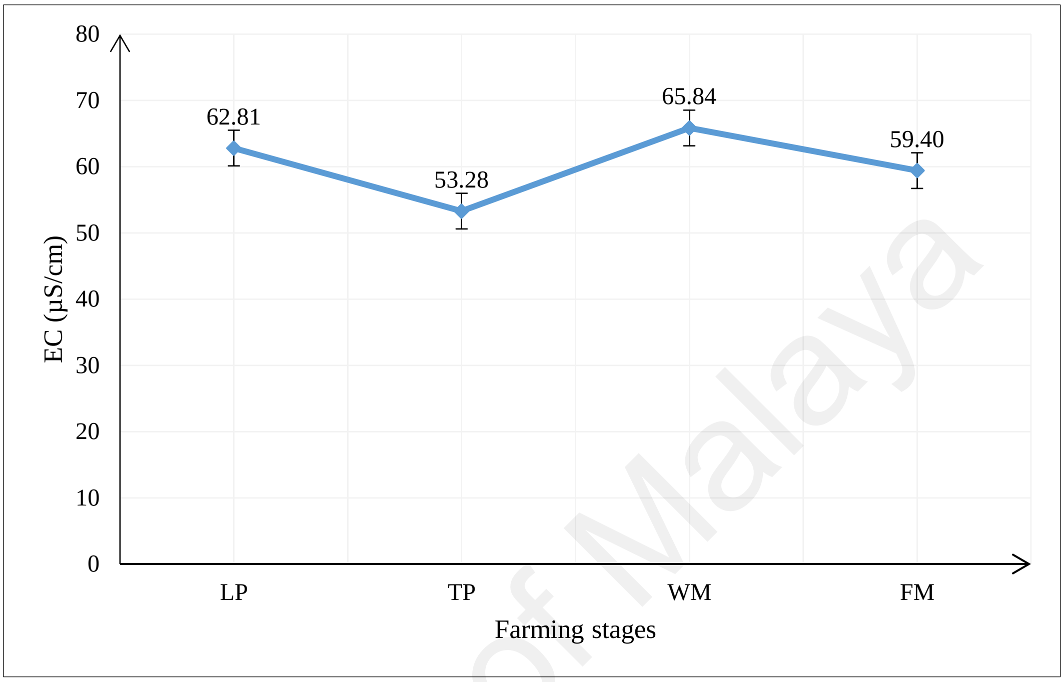


Figure 4.9: Mean electrical conductivity (EC) for impounded water during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

High values of EC shown at LP, WC and FM may be contributed by salts from the application of fertilisers and organic matter, whereas EC values were at their lowest during WC. Salinity is the concentration of all soluble salts in water or the soil. High level of salts in impounded water reduced nutrients availability to the crop (because of osmotic pressure) and caused a yield reduction. The primary effect of high water EC on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the lesser water is available to crops even though the soil may appear wet. Since crops can only transpire "pure" water, usable crop water in the soil solution decreased dramatically as EC increases (Bauder *et al.*, 2007). However, impounded water use in the experimental plots were all lower than the NWQS range for water EC (<1000 µS/cm) in Class 1 and Class IIA, which are acceptable for sensitive aquatic species. This indicates that the salinity of impounded water is tolerant and safe in terms of direct effects on crops during all SRI farming stages.

(d) ***Ammoniacal nitrogen (NH_4-N)***

The average concentration of NH_4-N at each stage of experimental plots was ranged between 0.04 ± 0.001 mg/L to 1.56 ± 0.26 mg/L (Figure 4.10). There was a trend of increase in NH_4-N from LP to FM with the highest concentration of 1.56 ± 0.26 mg/L followed by WC (0.24 ± 0.07 mg/L), whereas the lowest NH_4-N was recorded during LP (0.04 ± 0.001 mg/L).

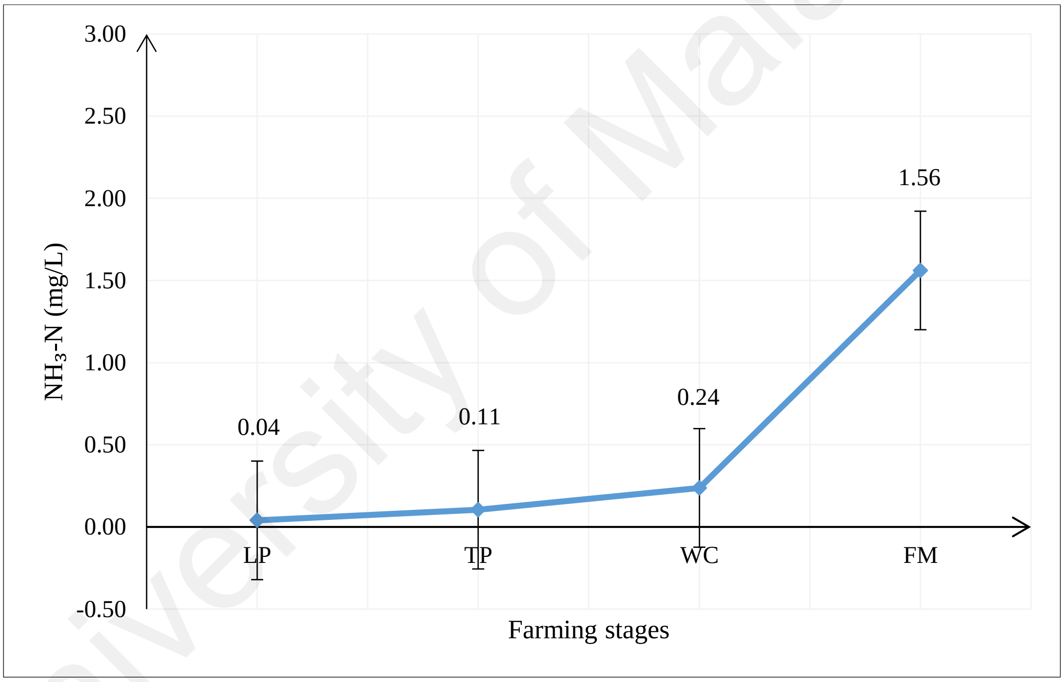


Figure 4.10: Mean ammoniacal nitrogen (NH_4-N) for impounded water during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

NH_4-N concentrations were high during the active growing seasons due to the fertilisation process in the field. It must be noted that a high NH_4-N runoff may lead to eutrophication in receiving water or in the experimental plot. Proposed standard for irrigation water by NWQS for NH_4-N is 2.7 mg/L (Table 3.5). Overall, the NH_4-N levels in the study area were relatively low and below 2 mg/L, thus were considered suitable for agricultural purposes.

(e) *Phosphate (PO_4)*

Figure 4.11 shows the phosphate mean values ranging from 0.20 ± 0.01 mg/L to 0.80 ± 0.03 mg/L. There was a sharp drop in PO_4 value from LP to TP. However, PO_4 values gradually increased towards the end of farming stages. The concentrations of PO_4 during LP were relatively higher than other stages with a mean of 0.80 ± 0.03 mg/L. For TP, WC and FM stages, the average concentrations were above the proposed standard values ranging from 0.20 ± 0.01 mg/L to 0.36 ± 0.06 mg/L.

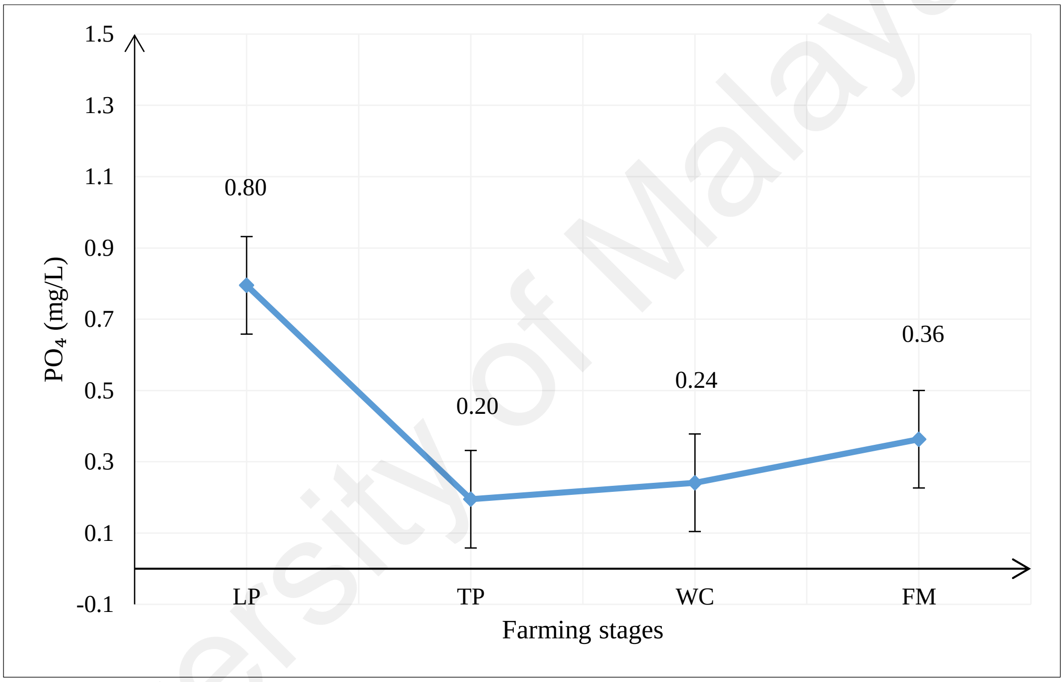


Figure 4.11: Mean phosphate (PO_4) for impounded water during SRI farming (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

Very high PO_4 value may be due to the use of nutrient uptake enhancer (NUE) during land treatment, which also suggests a high load of dissolved organic matter, whereas high PO_4 at FM is most likely to be arising from fertilisers applied to the experimental plots.

High PO_4 during LP and FM may cause algal blooms followed by a decrease in dissolved oxygen (Figure 4.8) where both stages display lower DO concentration compared to other stages. Phosphorus application frequently done during FM stage stimulates algal growth and productivity (Halwart & Gupta, 2004). Algae blooms will affect paddy growth as there is competition for nutrients and also uprooted paddy seedlings that are not yet securely anchored (Roger & Kulasooriya, 1980). The limit of the PO_4 concentration was 0.10 mg/L, which was considered high because it exceeds the permitted level of phosphate according to NWQS. All the values for PO_4 were reported exceeding the proposed standard (>0.10 mg/L).

4.2 Establishment of Relationship for Soil and Impounded Water Quality

4.2.1 Comparison Study Before and After SRI Method

In this study, water quality information before SRI method implementation was unavailable. Therefore, only comparison of soil quality was performed. Table 4.5 below shows the comparison between soil quality assessment before SRI and during SRI method. Comparison results showed that there was a significant difference in the soil quality for pH (t (4) = -18.80, p = 0.000), EC (t (4) = 7.03, p = 0.002), OC (t (4) = 4.03, p = 0.000), and CEC (t (4) = 13.65, p = 0.016) except for N.

Table 4.5: Paired t-test for soil quality assessment between SRI method and before SRI

Soil parameters	Mean		*t*-test	*p*-value
	Before SRI	During SRI		
pH*	5.54 ± 0.05	4.83 ± 0.22	-18.80	0.000
EC* (μS/cm)	6.80 ± 1.92	15.45 ± 4.06	7.03	0.002
N (%)	0.05 ± 0.01	0.07 ± 0.03	0.88	0.426
OC* (%)	0.43 ± 0.16	0.82 ± 0.33	4.03	0.000
CEC* (meq^+/100g)	2.26 ± 0.53	8.41 ± 1.23	13.65	0.016

*Significant at 0.05 level (paired t-test)

From the compared results, mean soil pH decreased (negatively significant) after implementing SRI from pH 5.54 ± 0.05 to pH 4.83 ± 0.22. In this assessment, all stages of SRI method showed that paddy soils are between pH 4.8 and pH 5. This indicates that the soils which were in weakly acidic had now become moderately acidic after the implementation of SRI method. High acidity is considered the primary obstacle to the production of early crop growth as the optimum pH for paddy soils is between pH 5.5-pH 6.0 (Aishah *et al.*, 2010). Another possible explanation on low soil pH during SRI method may be due to improper land management process during LP. Paddy experts believe that a proper tilling helps recycling plant nutrients and allows decomposition. If organic materials are not fully decomposed, the soil tends to become acidic and some nutrients will become less available (Bautista, 2016).

SRI method of controlling water supply into the plot and less water use may influence the acidity status of soil during SRI implementation. Meanwhile, draining and re-flooding paddy soil with a considerable amount of water as practiced in SRI method may increase the N availability (Young, 1976). Nevertheless, other soil parameters such as EC, OC and CEC were seen improved (positively significant) from the initial soil assessment. However, the CEC values increased do not contribute much to the soil quality. According to Murphy (2015), soil organic matter give poor impact to CEC in soil with pH below 5.5

4.2.1.1 Summary Finding on Soil Quality Improvements

Statistical t-test results proved that there is a positive improvement of soil quality at the study site with the implementation of SRI method. The key indicator for soil quality improvement in this study is the presence of soil organic matter, which is the main practice in SRI method. On the other hand, the organic matter from applied organic fertilisers helped in providing plant nutrients upon mineralisation and eventually improved soil properties.

However, this study believes that the best results for soil quality improvements could be obtained using the recommended practices altogether (Table 2.1), and as close as possible to what is recommended by SRI method principles (SRI-Rice, 2015). Sustainable farming system requires that all nutrients removed from the system are replaced (Vitousek *et al.,* 2009). Moreover, improving weathered soil to become healthy is important to provide a stable base to support plant roots, soil stores water and nutrients required for plant growth (Baishya, 2015). In the case of infertile soils at the study site, more nutrients need to be returned to the soils. Thus, to obtain more significant improvement in infertile soil, it is recommended that the application of compost should be increased. Incorporation of compost alters the soil environment that in turn influences the microbial population's activity in the soil and subsequent nutrient cycle (Rochester & Peoples, 2005) and will sustain rice productivity through replenishing soil organic matter (Kuldip *et al.*, 2001).

Alongside the use of organic matter to maintain good soil structure and to supply mineralisable N, there must be adequate inputs of other nutrients. Supplying N from organic sources may cause a similar acid input to the application of an equivalent amount of ammonium nitrate depending on the amount of nitrate leached. However, the increased buffer capacity of soil with larger amounts of organic matter practices by SRI method may reduce the effect of acidification. Thus, this may help to control the soil acidity especially in marginal soil, which is important in an organic farming system.

4.2.2 Relationship between SRI and Farming Stages

4.2.2.1 Soil and Impounded Water Relationship based on Kruskal-Wallis Test

The Kruskal-Wallis (Kruskal & Wallis, 1952) one-way analysis executed using SPSS was used to evaluate the differences among SRI farming stages (LP, TP, WC, FM and HV) with soil and water quality parameters. The selection of the non-parametric analysis was decided after conducting the ANOVA test on soil and impounded data. It was found that the soil and impounded water quality data do not fulfil the requirement upon applying the ANOVA test where size samples are small (<100) and not normally distributed (Adzhar Rambli, personal communication, January 5, 2016). Nonparametric method was also chosen because it did not require assumptions of normality and homoscedasticity, thereby avoiding any need to transform the data (Andrews & Carroll, 2001).

Summary on the results is presented in Table 4.6 and 4.7. Results revealed that there was a statistically significant difference in score between the SRI farming stages for all soil quality parameters such that, $\chi^2(2) = 9.743$, $p = 0.045$ for pH, $\chi^2(2) = 19.688$, $p = 0.001$ for EC, $\chi^2(2) = 11.055$, $p = 0.026$ for N, $\chi^2(2) = 19.427$, p = 0.001 for OC, $\chi^2(2) = 18.883$, $p = 0.001$ for P and $\chi^2(2) = 59.198$, $p = 0.0001$ for CEC. Results for impounded water quality parameters showed that all parameters are statistically different in score for DO ($\chi^2(2) = 17.87$, $p = 0.001$), NH_4-N ($\chi^2(2) = 28.87$, $p = 0.0001$) and PO_4 ($\chi^2(2) = 26.34$, $p = 0.0001$) except for pH and EC, whereas there is no significant difference between pH and EC under SRI method such that $\chi^2(2) = 2.82$, $p = 0.42$ and $\chi^2(2) = 6.96$, $p = 0.07$, respectively.

Follow-up tests were conducted to evaluate pairwise differences among five groups of SRI farming stages on all tested parameters. This helps to identify the group of SRI stages that gave the most influence. The finding showed that soil pH and EC values display significant difference during transplanting (TP) stage, whereas OC, P and CEC values were significantly differed during land preparation (LP) compared to other farming stages. Meanwhile, fertiliser management (FM) stage gave most significantly different values for soil N. Post hoc test for water nutrients revealed that activities during LP stage show most significant difference in values for NH_4-N and P. As for DO, most significant values were found during water circulation (WC) stage.

Table 4.6: Kruskal-Wallis test results for soil quality parameters

Soil Parameters	LP (N = 4)		TP (N= 14)		WC (N= 22)		FM (N=24)		HV (N= 16)		Kruskal-Wallis test	*P*-values
	Mean Rank	S.D	Mean Rank	S.D	Mean Rank	S.D	Mean Rank	S.D	Mean Rank	S.D		
pH	35.75	±0.24	25.46	±0.21	38.43	±0.18	47.92	±0.21	46.56	±0.18	9.74*	0.040
EC	45.50	±3.57	38.46	±2.78	52.50	±4.21	43.83	±4.56	19.53	±0.78	19.68*	0.000
N	48.00	±0.02	41.14	±0.01	46.43	±0.03	27.96	±0.02	48.72	±0.02	11.05*	0.020
OC	25.00	±0.22	50.96	±0.19	28.11	±0.22	53.08	±0.35	33.38	±0.35	19.42*	<0.001
P	2.75	±0.54	45.93	±2.02	30.91	±2.45	47.25	±2.10	48.25	±3.11	18.88*	<0.001
CEC	51.00	±1.28	14.93	±0.82	39.11	±0.45	67.10	±0.56	22.25	±0.48	59.19*	0.001

*Significant difference at $p<0.05$, LP- land preparation; TP – transplanting; WC- water circulation; FM: fertiliser management; HV – harvesting, S.D- standard deviation

Table 4.7: Kruskal-Wallis test results for impounded water quality parameters

Water Parameters	LP (N = 2)		TP (N= 6)		WC (N= 8)		FM (N=21)		Kruskal-Wallis test	*P*-values
	Mean Rank	S.D	Mean Rank	S.D	Mean Rank	S.D	Mean Rank	S.D		
pH	16.00	±0.14	22.67	±0.15	22.94	±0.30	16.74	±0.28	2.82	0.420
EC	23.75	±3.64	11.25	±3.64	26.00	±8.12	18.10	±6.72	6.96	0.070
DO	13.00	±1.52	17.75	±1.52	33.13	±0.58	14.55	±0.78	17.87*	0.001
NH_4-N	1.50	±0.00	5.67	±0.03	12.38	±0.07	27.00	±0.24	28.87*	0.001
PO_4	36.50	±0.03	3.92	±0.01	11.44	±0.02	24.52	±0.07	26.34*	0.001

*Significant difference at $p<0.05$, LP- land preparation; TP – transplanting; WC- water circulation; FM: fertiliser management, S.D – standard deviation

4.2.2.2 Relationship Based on Spearman Correlation

A deeper statistical analysis was used to identify the relationship between soil and water quality parameters. Spearman correlation of coefficient (Myers & Sirois, 2006) was used in this analysis. Table 4.8 and 4.9 depict the finding of results. From Table 4.8, significant correlation can be found between pH with OC, P and CEC. Meanwhile for OC, it shows significant correlation with CEC, EC and P. In the same time, it can be noticed that EC and CEC show a strong correlation similar to N and P.

Table 4.8: Spearman correlation matrix for soil quality parameters

Parameters	pH	EC	N	OC	P	CEC
pH	-					
EC	0.039	-				
N	-0.072	-0.217	-			
OC	0.263^{*}	0.398^{*}	0.129	-		
P	0.287^{*}	0.219	0.228^{*}	0.709^{*}	-	
CEC	0.294^{*}	0.329^{*}	-0.105	0.314^{*}	0.155	-

*. Correlation is significant at the 0.05 level (2-tailed)

From Table 4.8, result showed that soil organic carbon (OC) was significantly correlated with CEC (Spearman's rho (r_s) = 0.314, p = 0.05). Increasing soil OC can improve soil fertility and is often related to cation exchange capacity (CEC). CEC gives an indication on the potential ability of soil to hold plant nutrients where its values are determined by the amount of clay and humus contained in soils (Ross & Ketterings, 2011). The presence of clay and humus in soil is crucial as it acts as a cation reservoirs, which helps to improve the holding capacity of water and nutrient in soil (Shaidatul Azdawiyah *et al.*, 2014).

Much of the soil organic matter fraction contributing to the CEC contain variable electrical charge, which is why the effect of soil organic matter on CEC is pH dependent (Murphy, 2015). This explains the significant correlation between CEC and soil pH

(Spearman's rho (r_s) = 0.294, p = 0.008). Referring to Figure 4.1, it was shown that there was an increase in pH value from TP to HV stages. Increase in pH will increase the solubility of organic matter due to either particle dispersion increase or the repulsion of increasing negative changes on both organic matter and soil inorganic solid surfaces, which eventually increase the CEC (You *et al.,* 1999). In this study, soil CEC values (Figure 4.6) had shown conformity where it is increased from TP to FM.

The variance of soil pH values in sandy and acidic soil may affect soil nutrient availability to crops (Brady & Weil, 2002). It is known that the availability of nutrients to crops in soil is pH dependent especially nitrogen and phosphorus (Appendix J). This is in conformity with this study results where all stages of SRI method have soil pH below than 5 and showed very low level of soluble P in soil (optimum range of P is >40 mg/L). Other reason of low pH can be due to the frequency of bio-fertiliser and compost applied during sampling period (Table 3.3). This also led to the significant correlation between pH with OC as proved in the statistical analysis.

As for impounded water, results demonstrated that strong Spearman correlation was found between DO and PO_4. There was also a significant correlation between PO_4 with pH and NH_4-N (Table 4.9).

Table 4.9: Spearman **c**orrelation matrix for impounded water quality parameters

Parameters	**pH**	**EC**	**DO**	**NH_4-N**	**PO_4**
pH	-				
EC	-0.033	-			
DO	0.323	-0.030	-		
NH_4-N	-0.055	-0.048	-0.212	-	
PO_4	-0.347*	0.266	-0.430*	0.412*	-

*. Correlation is significant at the 0.05 level (2-tailed)

Strong interaction between PO_4 with DO (Spearman's rho (r_s) = 0.430, p = 0.008) indicates that variation values in PO_4 influence DO concentrations. DO concentration values across all stages were ranged between 6 to 10 mg/L (Figure 4.8) and categorised in permissible limits, whereas the concentration of PO_4 was found to exceed the suggested limit recommended by NWQS (Figure 4.11). A high presence of PO_4 may lead to algae growth and results in an algae bloom. Too many algae can cause a decrease in amount of DO in the water. However, the Spearman correlation statistic results do not reflect the descriptive analysis where mean concentration for DO and PO_4 were both high.

The significant correlation between NH_4-N and PO_4 (Spearman's rho (r_s) = 0.412, p = 0.01) may be attributed from most water samples that came from the FM stage where fertiliser application was very active. PO_4 also has a significant negative correlation (Spearman's rho (r_s) = -0.347, p = 0.03) with water pH. In Figure 4.7, the value of water pH during LP was very low, yet concentration of PO_4 was found high (Figure 4.11). Shrestha and Kazama (2007) explained that high PO_4 due to the existence of dissolved organic matter results in an anaerobic condition in the water, which in turn, causes the formation of ammonia and organic acids. Hydrolysis of these acidic materials had caused a decrease in pH. This shows that water pH was affected by chemicals in the water and the organisms interacting with the water system. This pattern was similar throughout all farming stages. As a whole, there is a strong Spearman correlation between soil and impounded water quality parameters tested under stages of SRI farming method.

4.2.2.3 Summary Finding on Soil and Impounded Water Quality under SRI Method

The concentration of soil nutrients was analysed with trends can be seen fluctuating from the early of SRI farming stage until the last. Statistical analysis showed that measured parameters were significantly differed at all farming stages. These indicate that different activities conducted during each farming stage could influence the changes of soil and impounded water qualities. Among the standout results were during transplanting (TP) where pH and CEC showed its lowest concentration, whereas P and C were low during land preparation (LP). During TP, soils were in moist condition. In addition, no active farming activity was observed during TP stage in which may influence the low pH and CEC. On the other hand, soil aeration and the process of alternately wet and dry of paddy plots during water circulation (WC) stage caused the high EC and N concentrations.

However, the soil quality at all farming stages did not give any effects to its impounded water quality as sample was taken at surface level in the plots, whereas the soil samples were taken at 0 - 40 cm depth. Higher values in impounded water quality analysis showed that farming stages gave more rapid effect in water than in soil quality analysis. This was supported by the results of water pH and EC that were higher than pH and EC in soil quality analysis. However, there was no significant correlation for pH and EC between farming stages found by the statistical analysis. Therefore, further study on the impact of pH and EC under different farming stages in marginal soil need to be conducted. Overall, the average concentration of soil and water nutrients does not exceed the limit of optimum nutrients required by paddy.

4.2.3 Comparison between SRI Method with Conventional Farming Method

Conventional farming method information for paddy soil and water quality were collected from various literature reviews (Appendix K). Mean values for the compile conventional farming method data were compared with SRI method experimental data.

4.2.3.1 Soil Quality Comparison of SRI with Conventional Farming Method

From Figure 4.12 below, conventional farming method was found ahead in all soil parameters compared to SRI method results.

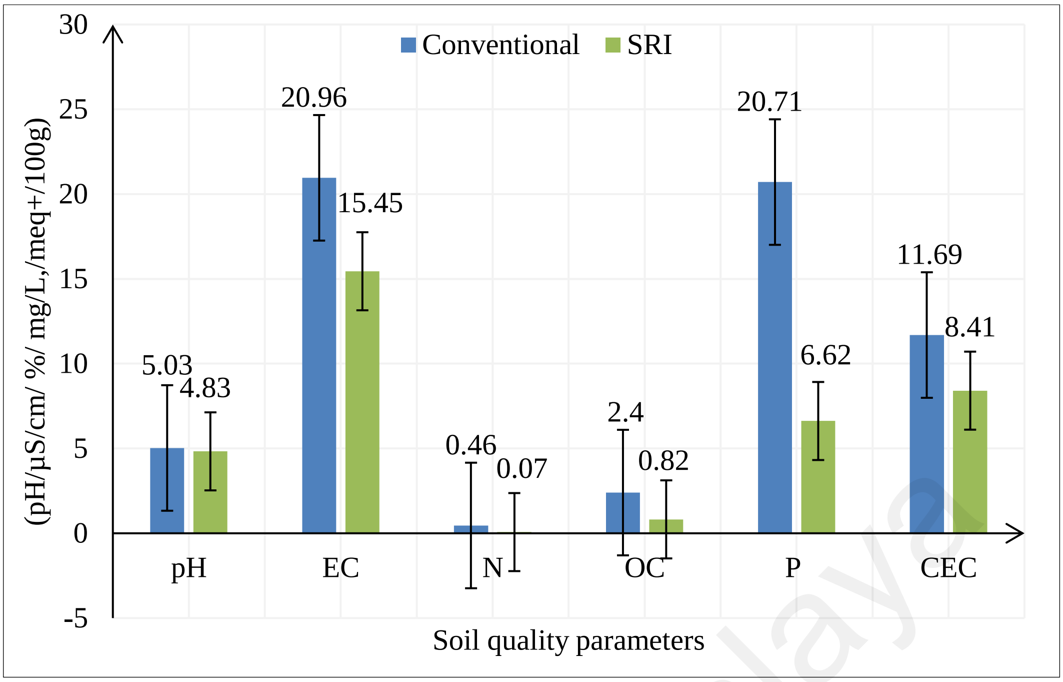


Figure 4.12: Mean comparison of soil quality parameters analysis between SRI vs. conventional farming method

Mean pH level in the conventional farming method was below the optimum pH limit for paddy soils. Most of the Southeast Asian country soils are marked with high acidity (soil pH< 3.5) acid sulphate soils, which contain high levels of aluminium (Al) (Elisa Azura *et al.*, 2014). Due to conventional paddy farming method where the paddy plots were impounded with water, anaerobic conditions took place and as a result, fermentation of carbohydrates occurred releasing acids that shift the pH to the acidic side (Benzon *et al.*, 2015). Application of mineral fertilisers containing ammonium can also contribute to further decrease in pH (Bationo & Buerkert, 2001).

Although EC values were high in conventional farming (20.95 ± 17.15 µS/cm) compared to SRI method (15.45 ± 4.06 µS/cm), it was still below the salinity limit (<3000 µS/cm) for paddy soil. The higher amount of salt content in soil may induce higher potential damage to paddy crops due to osmotic pressure (Shaidatul Azdawiyah *et al.*, 2014). The level of EC can be affected by a number of soil properties such as clay content, soil moisture, temperature, salinity and organic compounds.

Mean of N concentration (0.46 ± 0.6 %) in conventional farming method exceeded the range of soil N recommended for paddy soils (0.2 - 0.3 %), whereas SRI method showed very low concentration of N (0.07 ± 0.03 %). Higher concentration of N in conventional farming method might be due to the increased use of N fertilisers among paddy farmers. In the soil, too much nitrogen may create an imbalance of nutrients that causes a depletion of other essential minerals such as calcium, phosphorus and magnesium. When the nitrogen abundance reduces essential minerals, toxic elements such as aluminium can proliferate and harm plants as well as fish in nearby water bodies.

There are several factors that can cause high OC contents in soils in the conventional farming method. Most paddy cultivation areas in Malaysia and other Southeast Asian countries are planted in alluvial soils or near swampy lowlands with peaty organic matter, which has been referred to be in relation with pH (Kawaguchi & Kyuma, 1974). Other factors including relatively more humid climate also contribute to the accumulation of soil organic carbon in paddy soils. A further reason for the soil organic carbon increase was due to the slow decomposition of applied and native soil organic matter from prevailing anoxic conditions and formation of difficultly decomposable soil organic carbon under rice system (Surekha, 2013).

The conventional farming method showed a much higher level of soil P (20.71 ± 18.77 mg/L) detected compared to SRI method (6.61 ± 2.76 mg/L). Source of very high P from the application of chemical fertiliser will increase P accumulation in soil. However, it may not consistently increase paddy yields because flooding decreased soil P sorption and increased P diffusion (Yosef Tabar, 2012), hence leading to limited crop growth. Excessive P content in the soil also may harm beneficial root fungi, which helps the plant to absorb water and nutrients (Ancheng & Xi, 1994). Therefore, paddy farmers need to calculate their soil P content before the new farming cycle to ensure sufficient P uptakes from crops.

From the CEC results, conventional farming gave higher CEC values (>10 meq+/100 g), which indicate that the soils have good a availability of nutrients that can be taken by crops, thus leading to a good soil health (Ross & Ketterings, 2011). Higher frequency and amount of chemical fertiliser application applied in conventional farming may influence the higher CEC values.

4.2.3.2 Water Quality Comparisons of SRI with Conventional Farming Method

Figure 4.13 shows the results of water quality analysis comparison between SRI method and the conventional farming method. Finding showed that there is a large difference of DO concentrations between the two methods. Meanwhile, there was not much difference found for pH, NH_4-N and PO_4. However, SRI method for water quality assessment showed higher values for water pH, DO and NH_4-N, yet fairly lower concentration in PO_4 between both farming methods.

Both methods showed pH values within the permissible limit (Class IV) for irrigated agriculture and no obvious difference in pH levels. Higher DO concentration in SRI method can be explained by several factors such as a) small aquatic life that can be found in experimental paddy plots, b) input water that was released into the plot came from the pristine Lintang River that runs through the study site and c) cooler temperature (19^{o}C – 22^{o}C) (Appendix I) at study site as it is located further in the hilly area of Sik district that is still densed with primary forest. Habitats for warm water fish population should contain DO concentrations of above 4.0 mg/L.

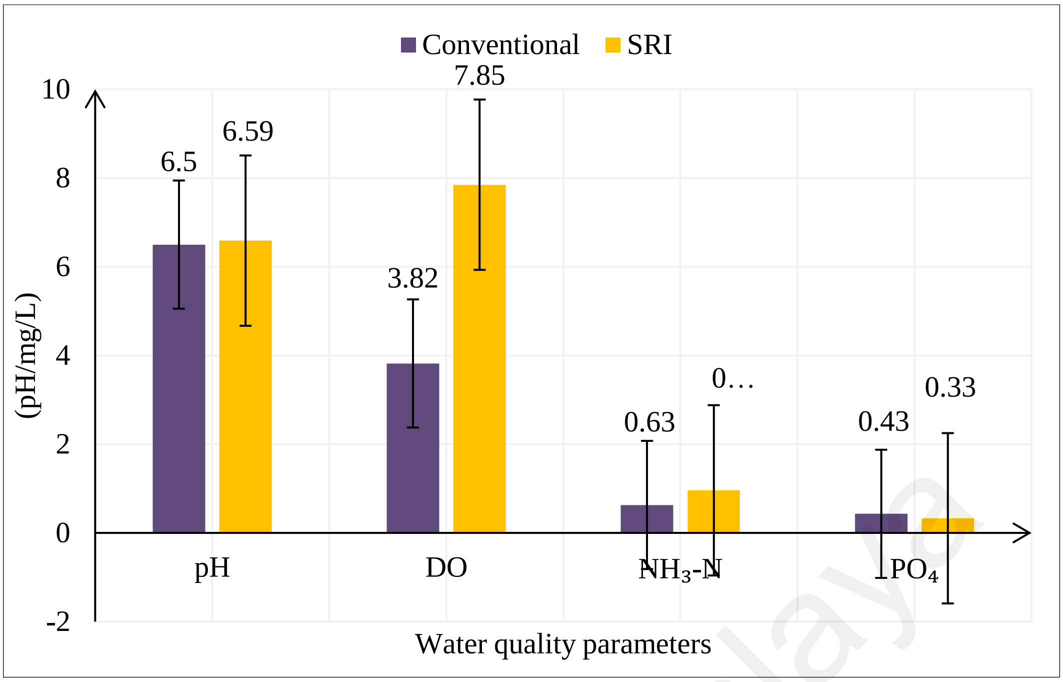


Figure 4.13: Mean comparison of water quality analysis between SRI vs. conventional farming method

Lower DO levels in the conventional farming method can be due to high crop density in plot area, whereas under SRI method, a widely spacing of paddy seedlings is recommended (Table 2.2). Aquatic organisms including microbes (bacteria and fungi) require DO to decompose organic material. Microbial decomposition is an important contributor to nutrient recycling. However, if there is an excess of decomposing organic material (from dying algae and other organisms) in water with infrequent or no turnover, the oxygen at lower water levels will get used up quicker. This situation often occurs under conventional paddy plots where water is at a standstill and impounded situation for many days.

A similar pattern can be seen in the comparison of NH_4-N where the concentration was much higher under SRI method. The high usage of compost, NUE and also N: P: K may contribute to this result. Farmers at the study site applied a large volume of N to return soil nutrient due to poor soil quality in the initial soil quality assessment before SRI method implementation. Despite the differences in terms of concentration values, both

NH_4-N concentrations were identified to be in a permissible range for irrigation water (Class IV) and can be accepted for livestock drinking according to NWQS standards.

Flooding or impounding the paddy plot commonly practised in conventional farming may also affect the high availability of PO_4 possibly by reducing ferric phosphate to the more soluble ferrous form. Following of this, PO_4 concentration exceeded recommended PO_4 limits (0.1 - 0.2 mg/L) by NWQS standard. There is a high possibility that the leaching of PO_4 will occur under this condition, thus affecting the nearest water bodies.

4.2.3.3 Summary Comparison Findings between SRI with Conventional Farming Method

SRI practices compared to conventional farming method showed some notable differences for soil and water quality. The quality of soil under conventional farming method was better (CEC >10 meq+/100g) compared to that under SRI method where the soil quality is still low (CEC <8 meq+/100g). Despite better outcome for soil fertility by the conventional farming method, it cannot be concluded that the soil is much healthier. Results from conventional showed a very high EC and P in the soil, which may lead to soil salinity and impose a greater risk to the reduction of paddy yield.

However, comparatively, there were better water quality results found in SRI rather than in the conventional farming method. Under SRI method, DO level showed much higher concentration results compared to conventional method. Adequate dissolved oxygen (DO) is necessary for good water quality as microbes such as fungi needs DO to decompose organic materials. Microbial decomposition is an important contributor to nutrient recycling. Additionally, P concentration was found to be much lower under SRI method.

Geographical location of site area and crop density may contribute to this finding. Under conventional method, the possibility of eutrophication to occur is more favourable compared to SRI method. Eutrophication causes loss of productivity due to low DO concentrations in water, but the blooming growth of algae (cyanobacteria) and toxins production are of particular concerns. Global warming may exacerbate the occurrence of harmful algal blooms in future years since high temperatures may increase algal growth and favour toxic algal species (Thomas & Litchman, 2016) especially in deep irrigation paddy practices that use high amount of N:P:K. However, as SRI method practices a minimal amount of water for irrigation purposes (1- 20 cm water depth), which may prevent the occurrence of algae bloom. Less usage of water can also be a mitigation strategy for farming in water scarcity areas due to the effect of global warming.

Problems related to extreme soil salinity and phosphorus as well as to avoid agrochemical runoff can be prevented by conducting soil and water quality tests and using proper fertilisation. Annual soil testing to monitor soil salinity and phosphorus levels are of recommended. For marginal soil, its soil fertility status should be known first prior to the establishment of any crop farming. This soil quality assessment will become the baseline for preparing the compost to be produced and applied during SRI farming method. Various sources of raw material for composting give different level of N: P: K. Therefore, manures and composts should be applied wisely. Using organic fertilisers with known N: P: K values can also improve the recommended rate of application significantly.

4.3 Comparative Results for SRI Method Compared to Simulated Soil and Water Quality Data

Figure 4.14 to 4.19 present the results for selected soil and water quality parameters after successfully undergoing a cold-run SWAT analysis. Cold run, a model run without calibrating any parameters were first done (Trung, 2005). This simulated quality analysis was then compared with average observed data of the experimental plots under SRI method. Soil and water quality parameters identified are phosphorus (P), nitrogen (N) and nitrate (NO_3) for soil and dissolve oxygen (DO), ammoniacal nitrogen (NH_4-N) and phosphate (PO_4) for water.

The overall data were compared during five stages of SRI farming activities, which are land preparation (LP), transplanting (TP), water circulation (WC), fertiliser management (FM) and harvesting (HV). For water analysis, no results were retrieved during HV as there was an absence of water in the paddy plot during this period. Comparison of the two data was presented in graph with its trend lines between simulated and observed results were discussed.

4.3.1 Soil Quality Comparison between Observed and Simulated Data

Identified simulated soil quality parameters used in the soil quality comparison with observed data are phosphorus (P), nitrogen (N) and nitrate (NO_3). Comparison graphs are displayed in Figure 4.14, 4.15 and 4.16.

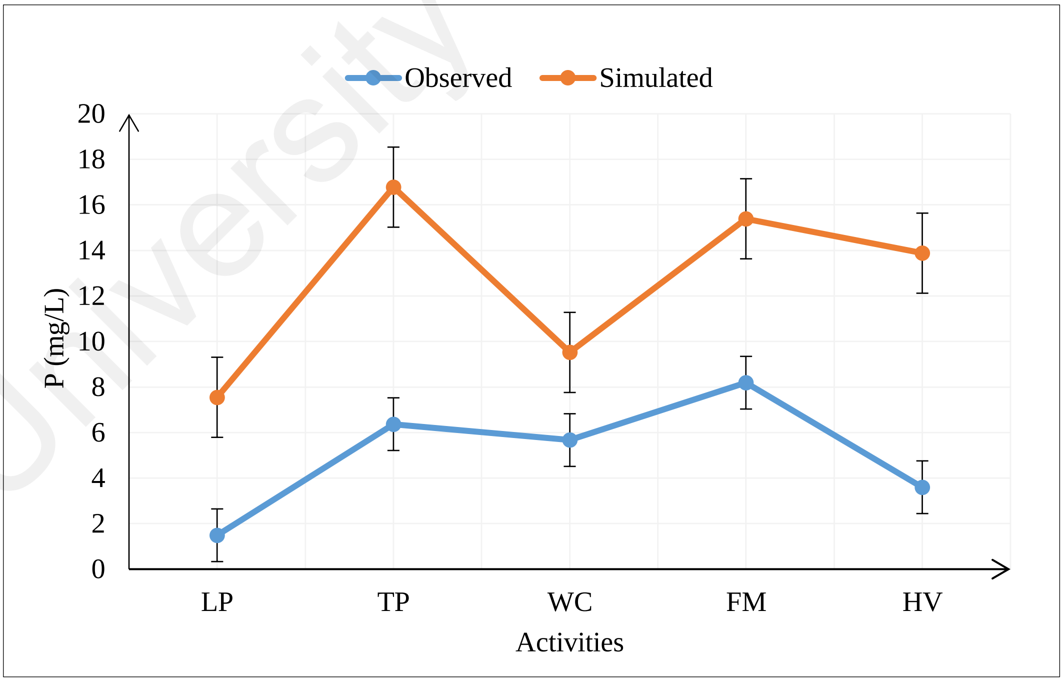


Figure 4.14: Graph comparison of observed vs. simulated soil data under SRI method for soil P (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

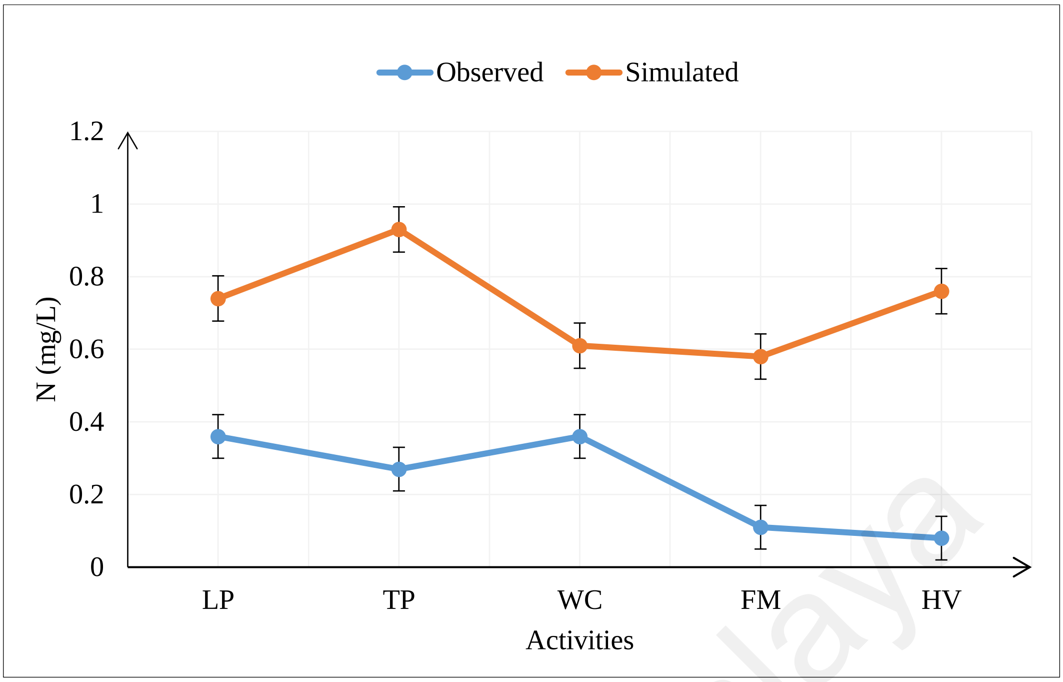


Figure 4.15: Graph comparison of observed vs. simulated soil data under SRI method for soil N (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

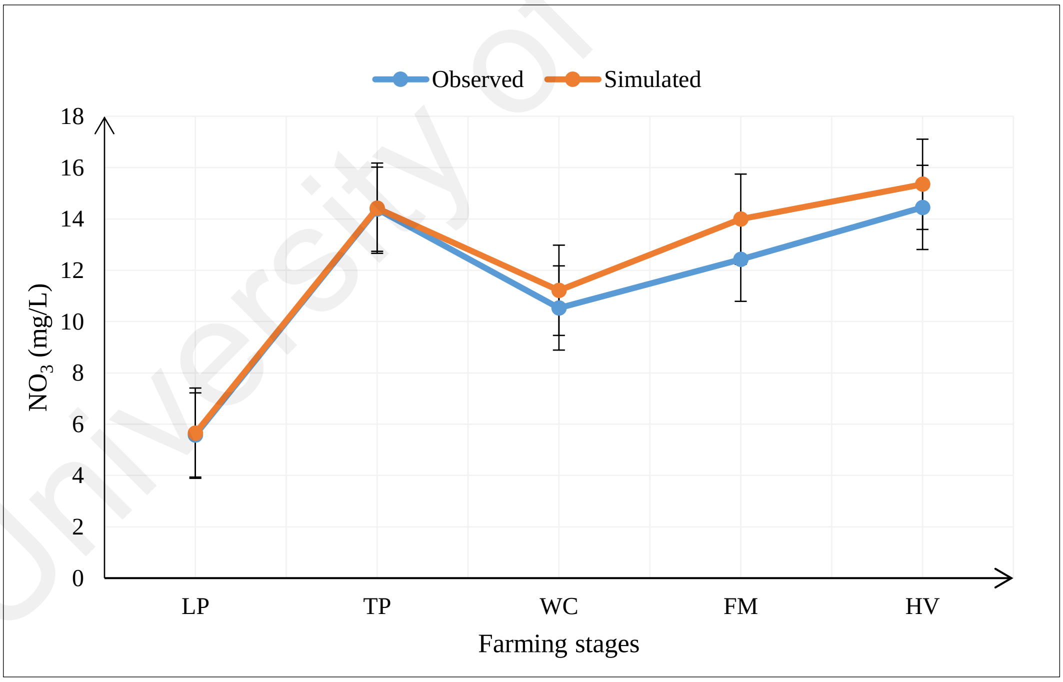


Figure 4.16: Graph comparison of observed vs. simulated soil data under SRI method for soil NO_3 (LP: land preparation, TP: transplanting, WC: water circulation, FM: fertiliser management and HV: harvesting)

Results from the soil quality comparison analysis showed that simulated data are much higher than observed data; yet the trends were seen to be similar. From the three graphs above (Figure 4.14, 4.15 and 4.16), NO_3 represented most identical trend when comparing simulated and observed data to P and N. Marginal gaps were identified for both P and N graph between observed and simulated data with similar trends obtained during all stages.

4.3.2 Water Quality Comparison between Observed and Simulated Data

As for water quality comparison (Figure 4.17, 4.18 and 4.19), observed data were found higher than simulated data with similar trends compared to the soil quality data done in Figure 4.14, 4.16 and 4.17. Simulated data for water quality showed much smaller values compared to observed water quality data. Hence, $\log_{10}$ formula was used to get a clearer relationship between observed and simulated water quality data as the variations are very large.

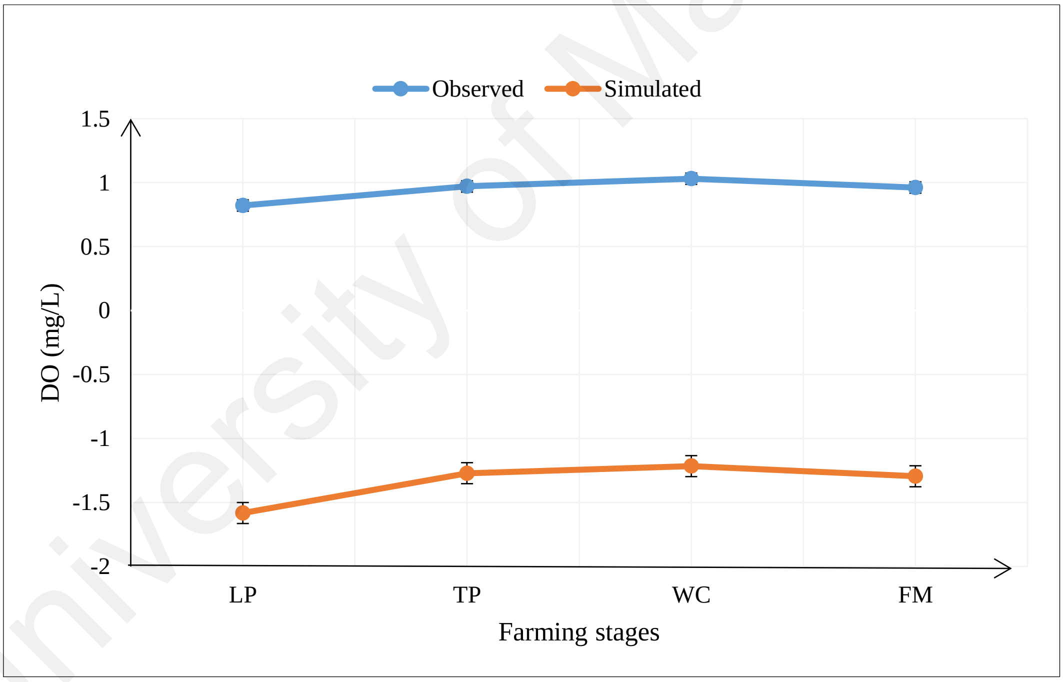


Figure 4.17: Log_{10} graph comparison of observed vs. simulated impounded water data under SRI method for water DO (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

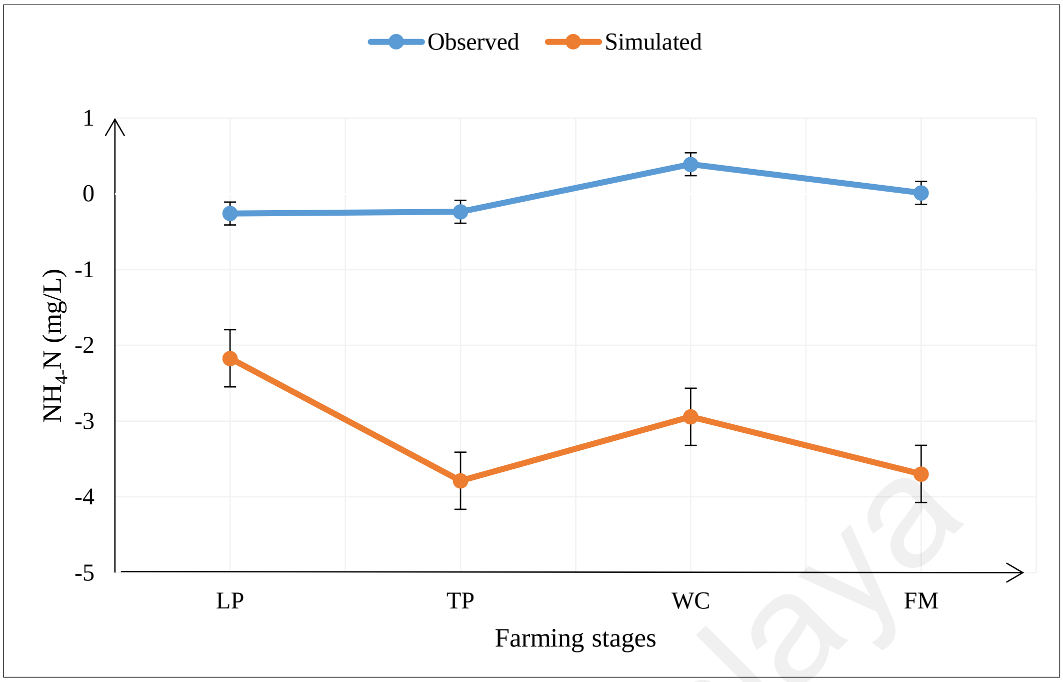


Figure 4.18: Log_{10} graph comparison of observed vs. simulated impounded water data under SRI method for water NH_4-N (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

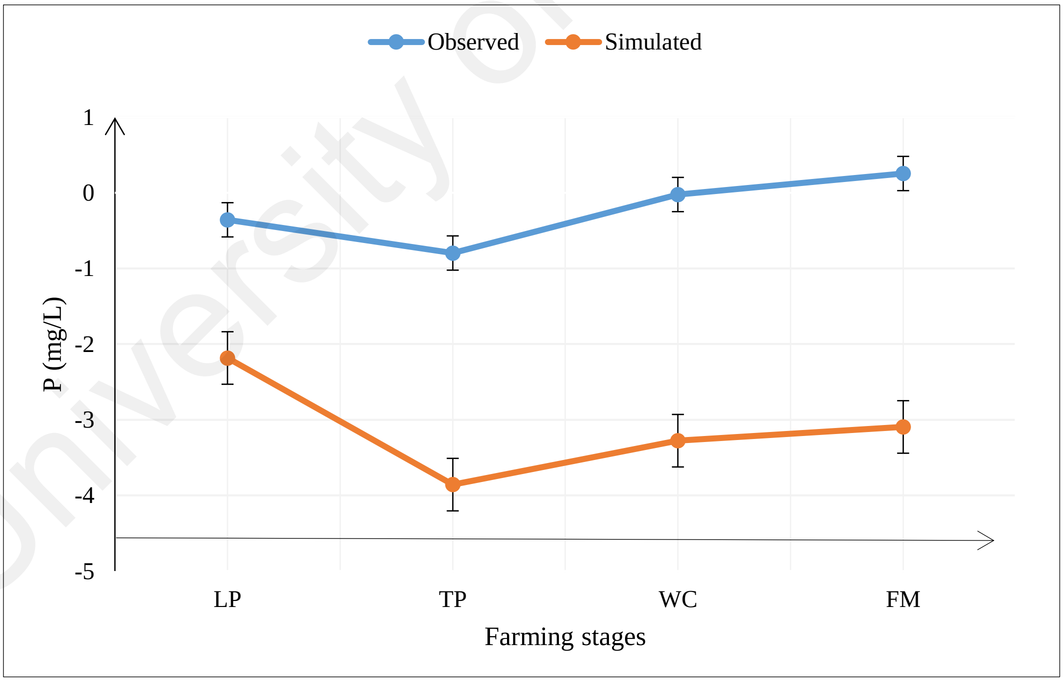


Figure 4.19: Log_{10} graph comparison of observed vs simulated impounded water data under SRI method for water PO_4 (LP: land preparation, TP: transplanting, WC: water circulation and FM: fertiliser management)

Results shown in Figure 4.17 for DO status presented that there were similar trends between observed and simulated data in the graph even with the existence of a significant variance. In Figure 4.18, TP showed a much different trend compared to both trend lines, whereas WC and FM depicted similar NH_4-N values trend. As for PO_4 comparison between observed and simulated data (Figure 4.19), both lines are following similar patterns but with a significant value variance. Overall, higher results of all farming stages in both soil and water quality comparison analysis between simulated and observed data may indicate the use of higher fertiliser input. The larger gap between simulated and observed data may be avoided when calibration process is conducted. Calibration is an effort to better parameterise a model to a given set of local conditions, thereby reducing the prediction uncertainty (White & Chaubey, 2005).

4.3.3 Summary Findings on Soil and Water Quality Changes Modelling using SWAT

This cold SWAT run was made due to lack of observation data. In the calibration process, model parameters were subjected to adjustment to obtain model results that correspond better to discharge rates observed in the field. Validation is the process of testing the calibrated properties with an independent set of data without further changes to the properties. Nonetheless, more observation data such as sediment yield, water discharge and surface flow are needed to run the calibration and validation process in SWAT model.

Under the local condition of data availability, the application of SWAT model for the Lintang Watershed has shown that SWAT is a useful tool that can be used to make a preliminary assessment on the potential agrochemical run-off of this watershed. Best model performance in terms of trend was shown in all selected parameters assessed, which suggests that observed soil and impounded water quality results are in line with the modelled simulation. The gap between observed and simulated data trend was believed to be minimised if the calibration process is made. Therefore, a further assessment on this should be continued in the future.

These assessments were consequently based on the best currently available knowledge for the study area. However, further improvements in model performance should be sought. The present work should be considered as a first step of identifying the gaps of information in the software for developing a bigger model application involving the entire Lintang Watershed. However, current conditions of data availability did not yet allow such an application. Current results can be used to establish parameter priorities for obtaining additional field data sets, which should allow such an application in the long term.

4.4 Limitations

There are several gaps that need to be highlighted especially on the lack of paddy yield data, data collection for water quality analysis and the farming management during the study.

As mentioned earlier, paddy yield was not recorded as the farmers harvest it before the collection of data. In the past years, several studies have shown that there is a correlation between SRI method and high yield as mentioned in Chapter 2. However, not many studies were done evaluating paddy yield on marginal soil with SRI farming method. This data should be helpful if the improvement of soil and water quality to SRI yields can be correlated during this study for more concrete evidence on the benefits of SRI method.

If this study is performed again, analysis on whether or not the water temperature is a significant factor affecting the dissolved oxygen levels and paddy yield should be conducted. The temperature was recorded while sampling impounded water and recorded historical data for SWAT analysis (Appendix I), but the data were not deeply analysed for this report. Temperature can increase or decrease dissolved oxygen; thus, the present results could have been influenced by water temperature along with other factors previously mentioned.

It is worth mentioning that the SRI method in this study could not follow the full principles of SRI especially on the implementation of fertiliser. SRI principle recommended that farmers enrich soils with organic matter; however, the use of granule fertiliser with moderate amount of N: P: K (6-4-14) was observed. The reasons are that the low quality of soils at the study site needs more intensive care in terms of soil nutrients, thus leading to a higher amount of N: P: K application via frequent application of compost and bio-fertiliser. Moreover, results were quite promising in the improvement of soil CEC and water DO regardless of the low pH values in soils. The overall results are a good indicator proving that SRI method is able to provide a better system to improve soil and water quality for marginal soils. It does not only help to improve the soil quality, but also enhance the environmental surrounding and transforming marginal land into a better ecosystem. It is expected that soil and water quality results can be further enhanced if the full principles of SRI are applied in the future study.

CHAPTER 5: CONCLUSION

The investigation on the quality and improvement of the marginal land of a paddy plantation for its soil and impounded water using the system of rice intensification (SRI) method has been successfully carried out. With results and discussions of this study described in Chapter 4, this chapter presents a general conclusion from the outcomes.

5.1 Summary

The purpose of this study is to assess the improvement of soil and impounded water quality of marginal land through the environment-friendly system of rice intensification (SRI) method. It was found that there was a positive improvement of soil quality at study site with the implementation of SRI method. However, it is believed that best results for soil quality improvements could be obtained using the recommended practices altogether (Table 2.1) and as close as possible to what is recommended by SRI method principles (SRI-Rice, 2015). The recommended practices represent an 'ideal type' of SRI method. The more closely farmers follow SRI method principles, the better the results obtained. Each stage of SRI method makes a contribution in improving the growing environment for paddy crops.

In addition, when assessment was done on soil and impounded water quality during every farming stages under SRI method, results showed that the average concentration of soil and impounded water quality did not exceed the limit of optimum nutrient needs by paddy. Regardless of the different changes of soil and impounded water quality throughout all stages, there is no major impact of SRI to the environment in terms of pollution. Water quality analysis showed that the impounded water quality is in permissible range for irrigation water and livestock drinking. Therefore, it is recommended that the farming practices by SRI method are used to help improving the marginal land, which is infertile.

5.2 Conclusions

Based on the findings from this thesis, the results provide valuable information regarding SRI method practices on soil and water quality status on marginal soils. SRI method can help to enhance the soil quality as it encourages the use of organic fertilisers. Thus, this will attribute to the increase of nutrients in infertile soil. SRI method has shown to aid in enhancing soil quality and maintaining impounded water quality status under the acceptable range for agricultural purposes. Hence, the aim of this study has been successfully investigated. Nevertheless, more rigorous and systematic studies are needed on long–term effects of SRI method such as a better mechanical weeder or enhanced management farming approach especially on marginal soils in Malaysia to ensure a sustainable paddy farming practices.

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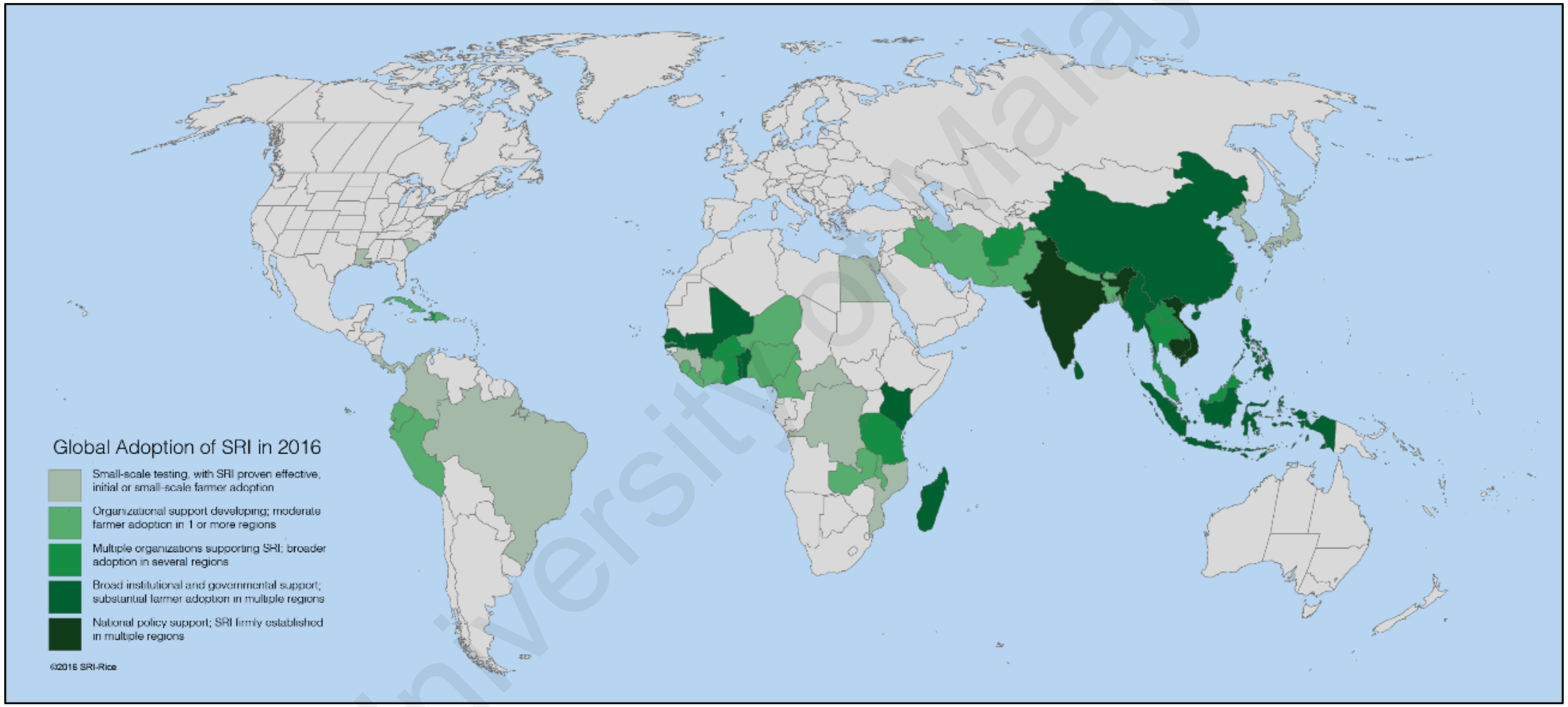
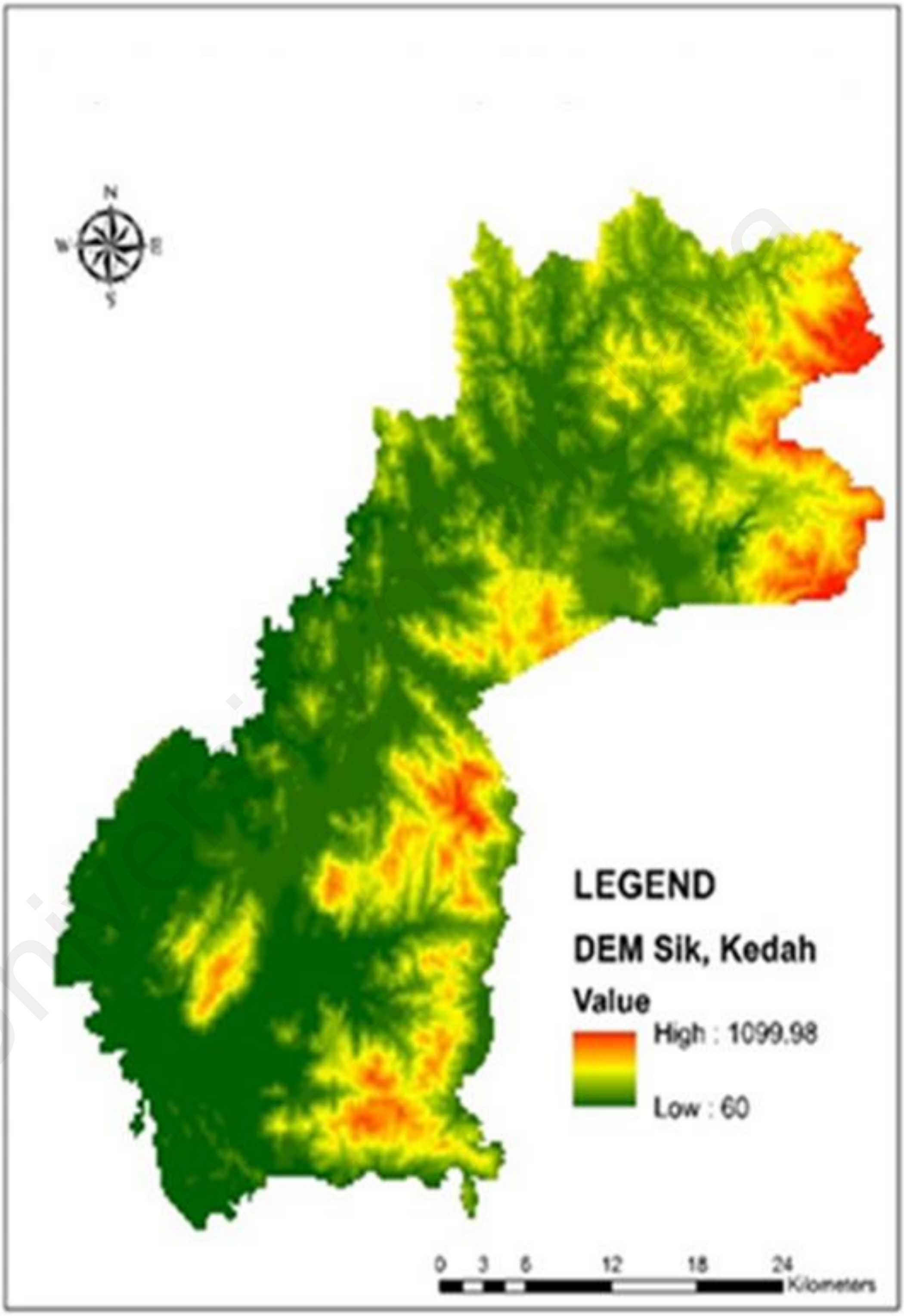
LIST OF PUBLICATION AND PAPER PRESENTED

1. Alia, A., Ghufran, R., Radzali, M., Norlida, M.H., & Siti Aliah, M.H (2014). Assessment of soil and water quality on system of rice intensification (SRI) using soil and water assessment tool (SWAT) at Belantik, Kedah, Malaysia: Preliminary data status. In *Proceedings of International Conference 2014 Nationwide GIS Application* (pp. 955-964). Ho Chi Minh, Vietnam: Can Tho University

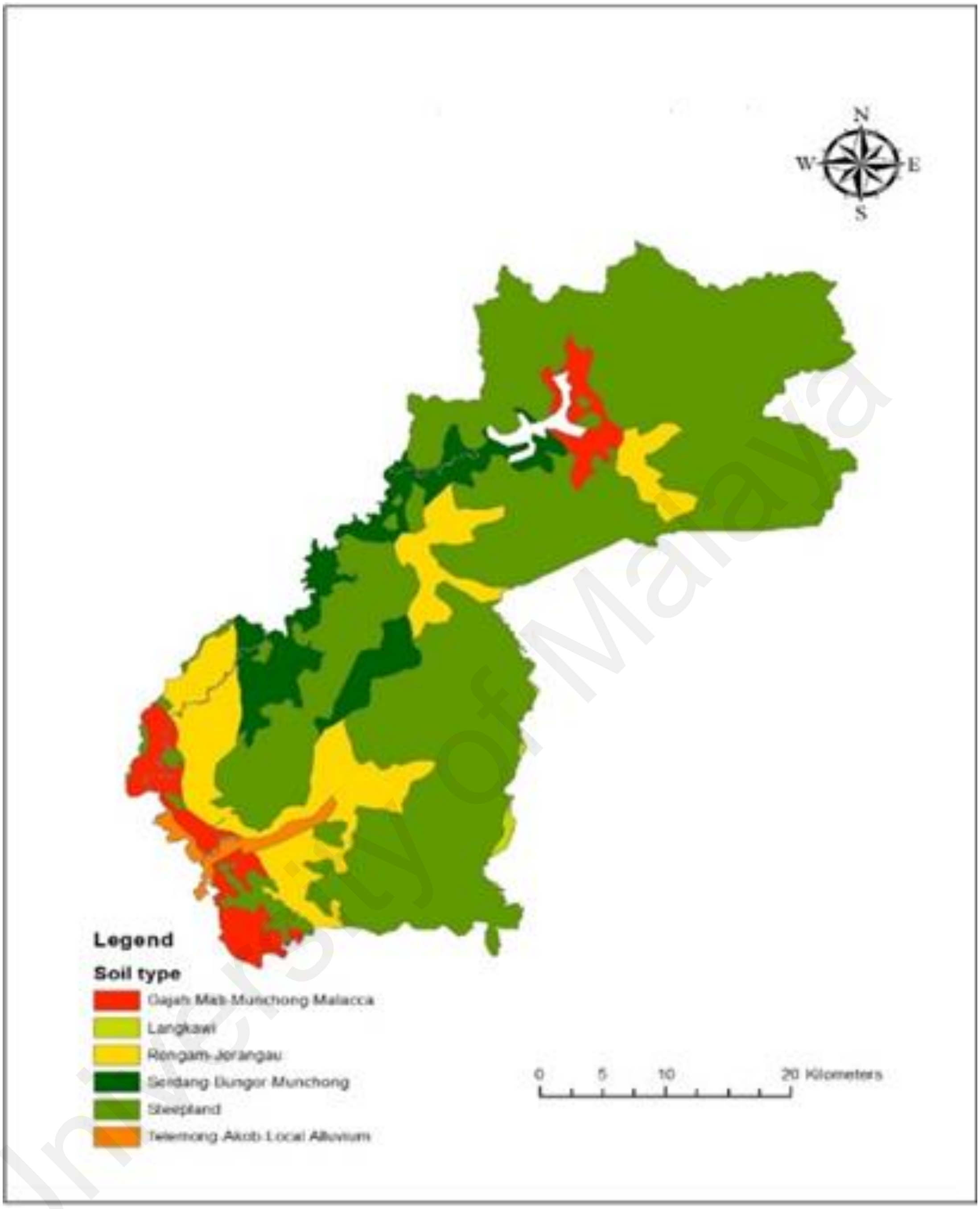
APPENDIX A: MAP OF SRI IMPLEMENTATION STUDY AROUND THE WORLD



APPENDIX B: MAP OF DIGITAL ELEVATION MODEL (DEM) FOR SIK KEDAH



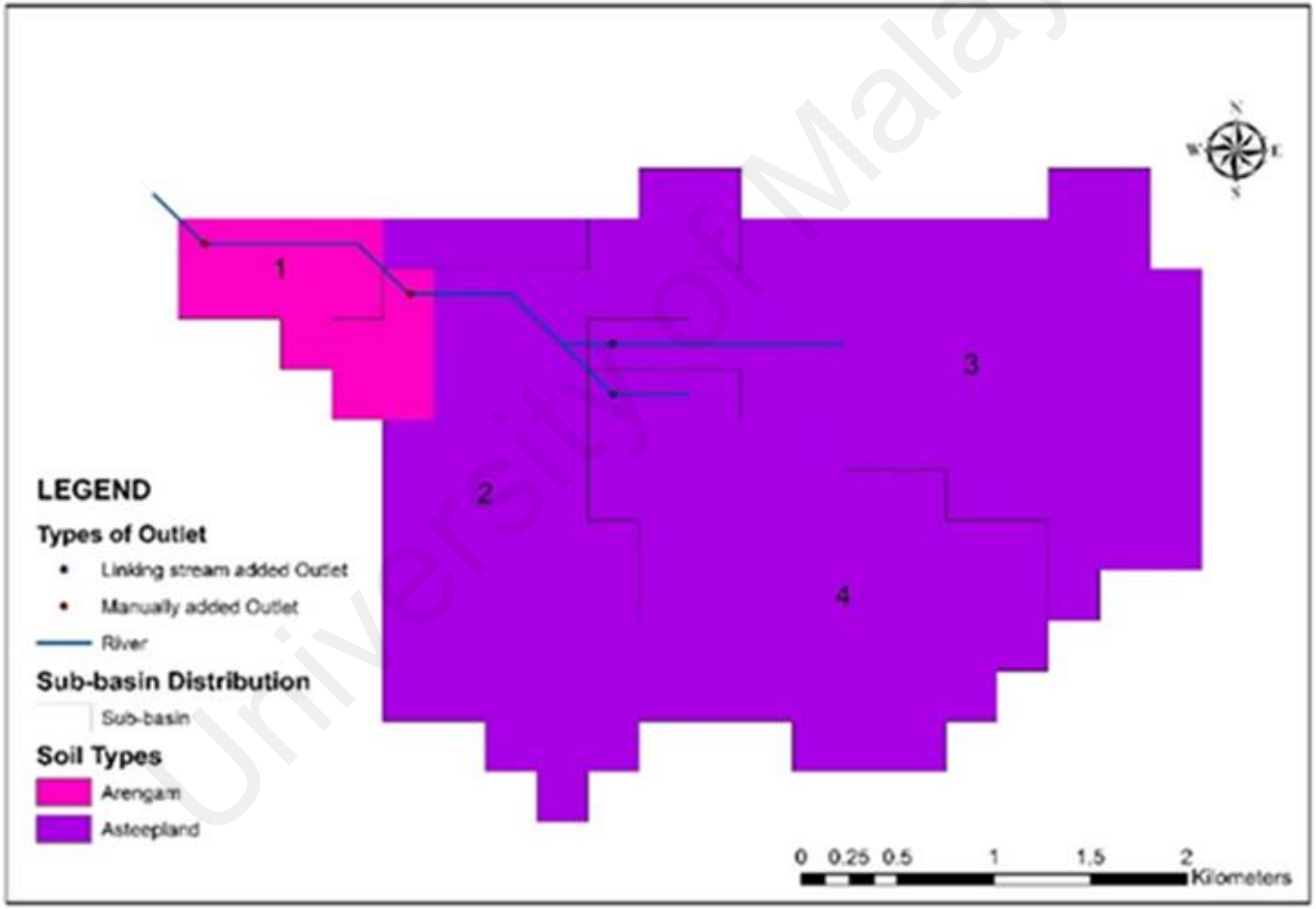
APPENDIX C: MAP OF SOIL DISTRIBUTION FOR SIK, KEDAH



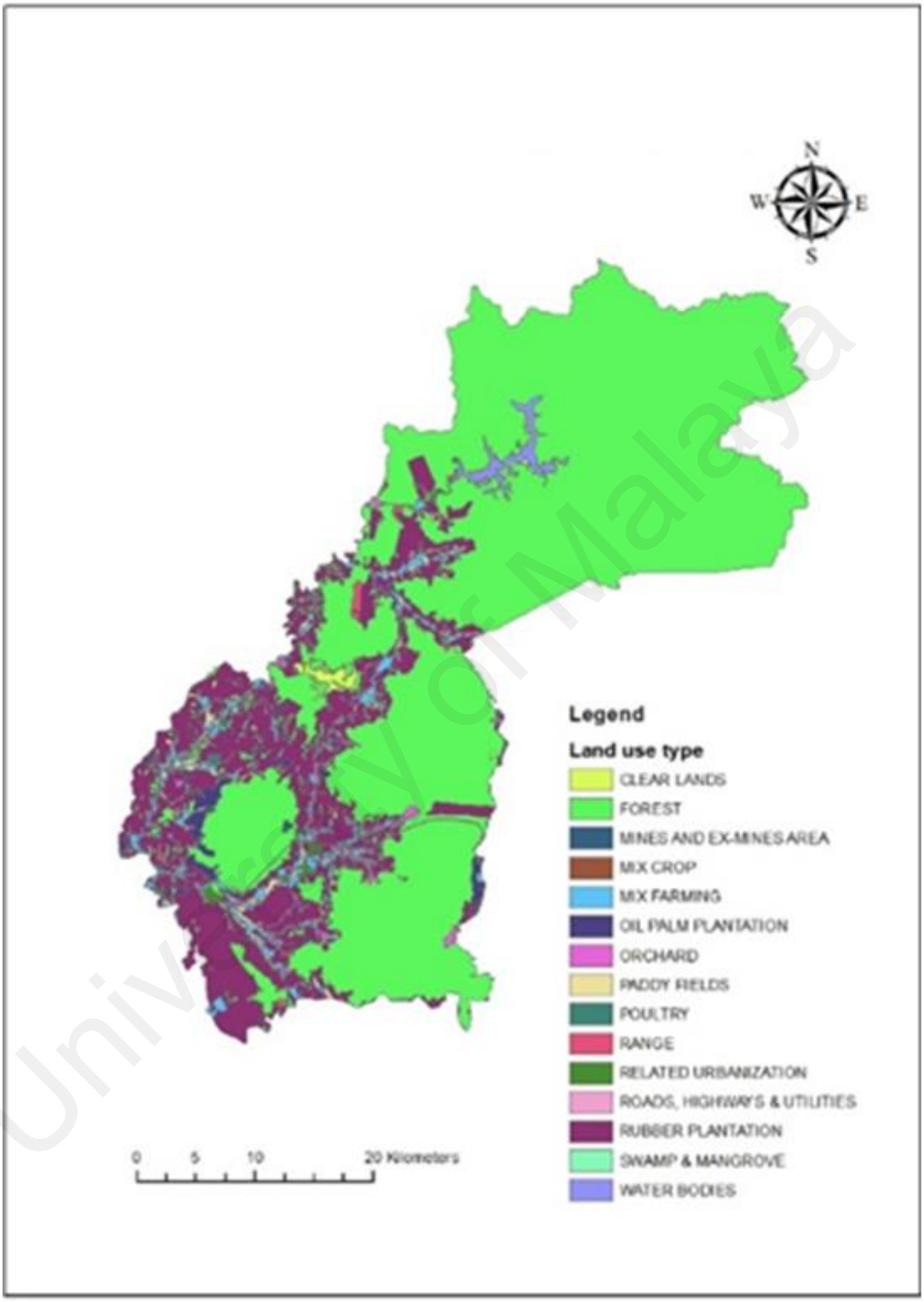
APPENDIX D: TABLE OF SOIL TYPES, AREA AND FRACTION FOR SIK, KEDAH

No	Soil type	Total soil area (Km^2)	Fraction of total soil (%)
1.	Gajah Mati-Munchong-Malacca	7.89×10^6	21.47
2.	Langkawi	1.24×10^5	3.44
3.	Rengam-Jerangau	3.37×10^6	9.18
4.	Serdang-Bungor-Munchong	2.08×10^6	5.67
5.	Steepland	2.15×10^7	58.42
6.	Telemong-Akob-Local Alluvium	6.65×10^5	1.81
	Total	$\mathbf{3.67 \times 10^7}$	**100**

APPENDIX E: MAP OF SOIL TYPES DISTRIBUTION FOR LINTANG WATERSHED



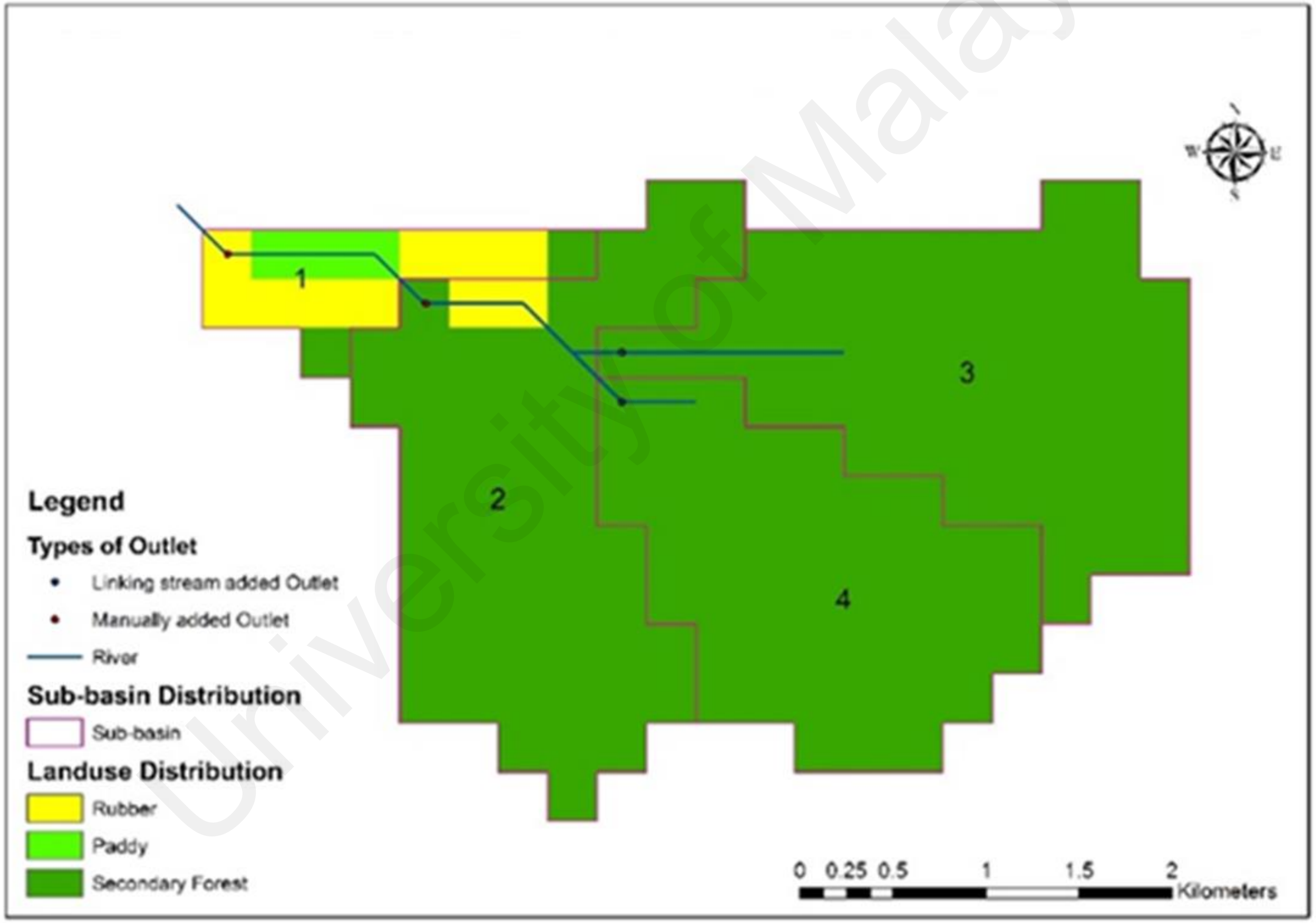
APPENDIX F: MAP OF LAND USE DISTRIBUTION FOR SIK, KEDAH



APPENDIX G: TABLE OF LAND USE AREA AND LAND FRACTION FOR SIK, KEDAH

No	Name	Area (Km^2)	Fraction of total land (%)
1.	Orchard	8.88×10^4	0.29
2.	Rubber plantation	6.66×10^6	21.67
3.	Swamp & mangrove	2.16×10^4	0.07
4.	Forest	2.23×10^7	72.52
5.	Roads, highways and utilities	5.37×10^4	0.17
6.	Clear lands	1.07×10^5	0.35
7.	Poultry area	1.41×10^4	0.05
8.	Oil palm plantation	2.01×10^5	0.65
9.	Mines and ex mines area	2.81×10^4	0.09
10.	Paddy fields	2.39×10^5	0.78
11.	Mix crop	1.24×10^4	0.04
12.	Related urbanization	8.82×10^4	0.29
13.	Mix farming	5.13×10^5	1.67
14.	Range	1.79×10^5	0.58
15.	Water bodies	2.39×10^5	0.78
	Total	$\mathbf{3.07 \times 10^7}$	**100**

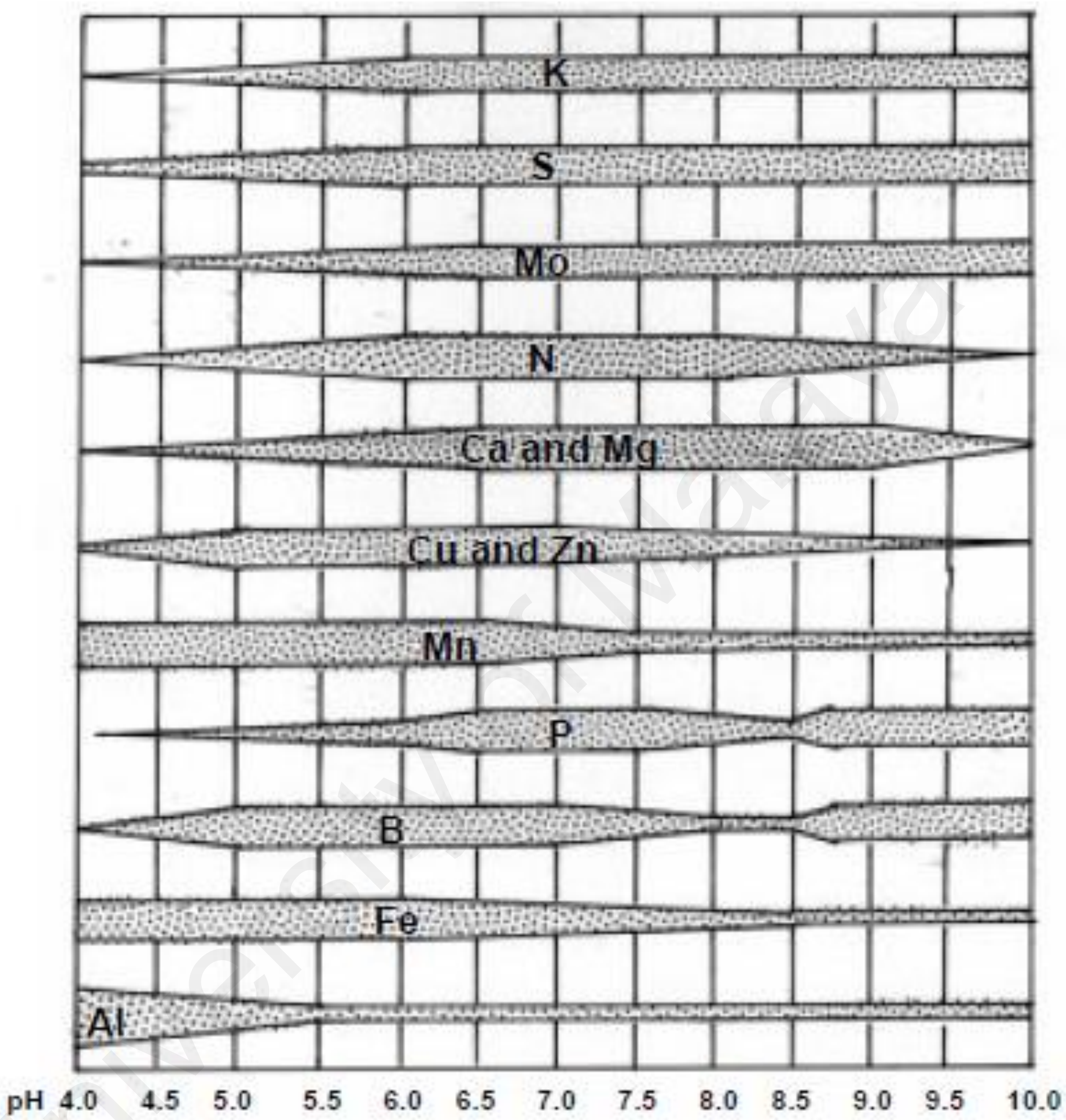
APPENDIX H: MAP OF LAND USE DISTRIBUTION FOR LINTANG WATERSHED



APPENDIX I: SUMMARISED CLIMATIC PARAMETERS OF LINTANG WATERSHED FOR SWAT SIMULATION (2013-2014)

Month	**Daily maximum temperature (°C)**	**Daily minimum temperature (°C)**	**Solar Radiation (MJ/m^2)**	**Wind Speed (m/s)**	**Precipitation (mm)**
Jan	31.06	20.06	18.68	1.65	4.97
Feb	33.65	19.70	19.42	1.47	10.86
Mar	35.72	20.36	20.54	1.41	3.42
Apr	32.19	21.72	20.28	0.90	41.32
May	31.67	22.09	23.12	0.85	16.84
Jun	31.48	21.06	22.34	1.10	7.56
Jul	31.83	20.15	21.97	1.16	6.62
Aug	30.88	20.44	21.35	1.13	8.12
Sep	29.38	20.96	20.29	1.08	22.19
Oct	28.65	21.45	18.34	0.97	15.22
Nov	29.97	21.27	18.20	1.00	38.71
Dec	28.90	21.30	16.54	1.62	23.10

APPENDIX J: EFFECT OF PH TO SOIL NUTRIENT AVAILABILITY (BRADY & WEIL, 2002)



APPENDIX K: LIST OF REFERENCES FOR CONVENTIONAL PADDY FARMING STUDIES

Journal	Title	Author	Year
Book	Paddy soil in tropical Asia	Kawaguchi & Kvuma	1974
Malaysian Society of Soil Science	Fertility improvement of fluvial paddy soil of Kelantan plain by organic matter addition	Ahmad, Arulandoo, & Aminuddin	1997
MARDI report	Organic rice farming system	Samy, J., Xavier, A., & Rahman	1997
Malaysian Journal of Soil Science	Spatial variability of soil N,P & K in a paddy field	Swapan, Anuar, Kamaruzaman, Desa, & Wan Ishak	2001
Malaysian Society of Soil Science	An assessment of paddy soil degradation and its impact on sustainable rice production	Aminuddin et al.	2003
Journal - The Institution of Engineers, Malaysia	Predicting paddy soil productivity	Chan, Lee, & Mohammud	2006
4th INWEPF Steering Meeting and symposium	Comparison between conventional and organic paddy fields in irrigated rice ecosystem	Lawanprasert, Kunket, Arayarangsarit, & Prasertsak	2007
J. Biosci.	Correlation between soil microbial and nutrients variation in a rice paddy: Implication for assessing soil health	Doi & Ranamukhaarachchi	2009
Malaysian Journal of Soil Science	Spatial variability of selected chemical characteristics of paddy soils in sawah sempadan, Selangor	Aishah et al.	2010
Malaysian Society of Soil Science	Model comparisons for assessment of N:P:K requirement of upland rice for maximum yield	Hartinee, Hanafi, Shukor, & Mahmud	2010