Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Rehabilitation of Paddy Fields using Subcritical Water Pretreated Oil Palm Empty Fruit Bunch

Adilah Ahmad Asmadi[1], Pramila Tamunaidu[1,*]

[1] Department of Chemical and Environmental Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, 54100 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 3 May 2023
Received in revised form 30 October 2023
Accepted 17 November 2023
Available online 29 November 2023

Keywords:
Low rice yield; acidic soil; oil palm empty fruit bunch; subcritical water

ABSTRACT

The paddy consumption in Malaysia is forecasted to increase, however, constant paddy production area coupled with low rice yield in the past years has raised concerns. Various efforts has been implemented by paddy farmers which may not be sustainable. This include excessive applications of chemical inputs that damage the environment and increase the cost of production. Moreover, one of the problems faced in paddy production is acidic soil. Commonly, chemical treatments are used to increase the soil pH. An alternative method to alleviate the acidic soil is by applying organic matters. Oil palm empty fruit bunch (EFB) is abundantly generated from oil palm mill and is often disposed to landfill or incinerated. Due to its high nutrient content, EFB can be transformed into organic fertilizer or soil amendment. Therefore, the objective of this study was to investigate the potential of using subcritical water (SCW) pre-treated EFB to alleviate acidic soil. Two experimental study which are lab-scale and agriculture-scale were conducted. For agriculture-scale, the results showed significant increase of soil pH in five out of six plots monitored. Plots which were initially too acidic were significantly improved to pH 5.5 – 6.4. For lab-scale, the acidic conditions in Sungai Balang, Johor were replicated in pots of soil. Four types of soil treatment (control, chemical, raw EFB and SCW-treated EFB) were applied to the acidic soil and the changes in soil pH were monitored for 30 days. Result from the lab- scale study shows that SCW-treated EFB applied at ratio of 1:3 is able to increase and maintain soil pH at 6.1 – 6.4, which is within the optimum range for paddy growth. This shows that application of SCW-treated EFB can be used as organic fertilizer and adopted as one of the sustainable paddy farming practices to improve paddy soil conditions.

1. Introduction

Rice (*Oryza sativa*) is a staple food in most Asian countries, more than 80 % of the world's rice is consumed in the Asian region [5]. Especially in developing countries, most people depend on rice for calories intake and as a source of protein. Rice has also been the main source of employment for many of the rural population in Malaysia. The rice industry is essential for the livelihood of 172,000 paddy farmers in Malaysia.

* *Corresponding author.*
E-mail address: pramila@utm.my

https://doi.org/10.37934/ard.110.1.124

In 2016, the Southeast Asia (SEA) region contributes 16 million MT, which is around 39.9 % of the world's rice export, making this region the centre of the world's rice economy for the past centuries. The top countries with highest rice exports are Thailand and Vietnam which contributes to the world's total export of rice as much as 24.5 % and 12.9 % respectively. However, not all SEA countries are rice exporters. Malaysia, the Philippines and Indonesia are among the SEA countries that imports its rice from other countries. In 2016, Malaysia stood at 2.2 % of the world's total rice import. The country's rice self-sufficiency level remains at a staggering value since the year 2000 which varies from 70 - 75 %.

The practice of rice cultivation in Malaysia is currently twice a year which comprises of the main season starting from July until January, whereby the off seasons begins from February until June. The current popular rice varieties which are produced by the Malaysian Agricultural Research and Development Institute (MARDI) are MR 219, MR 220 and MR 232. The most popular rice variety among paddy growers is MR 219 as it has a high yield characteristic. In 2016, around 1.8 million MT of rice were produced locally, mainly from the primary ten key granary areas such as Muda Agricultural Development Authority (MADA), which produces around 38.8 % of the total rice production. However, in the same year, the total rice consumption was around 2.7 million MT with 700,000 hectares of paddy area harvested, thus, proving that there is a huge gap between total rice consumption and the total domestic rice production [5].

The agriculture minister specified that as much as 740,000 tons of rice were imported from rice exporting countries to hamper the total rice supply deficit in 2019. This costs the government as much as RM 1.18 billion. Therefore, the government have ramped up efforts by establishing the National Agricultural Policy where a target has been set to increase the domestic rice production by up to 75 % in the next three or four years. Moreover, the Minister of Agriculture, Datuk Salahuddin stated that the government encourages new technologies, such as using better variety of seeds and fertilizers in order to boost the rice production in Malaysia.

Moreover, according to the Department of Statistics Malaysia (2016), it is forecasted that Malaysia population will increase from 28.6 - 41.5 million people with a population growth rate from 1.8 - 0.8 % in 2010 and 2040 respectively. Despite the increase in number of populations in Malaysia, the harvested area for paddy has seen to have a constant area of size since 1961. Due to the constant size of harvested paddy area with the increasing number of populations in the future, it is projected that Malaysia will face an increase of widening gap between the rice production and consumption. Thus, the increase in Malaysia population requires the increase of domestic rice production to cater for the rice demand.

The rice industry faces many challenges which include stagnation or decline in productivity, soil and water resources degradation, and the increasing chemicals usage which causes adverse changes in climate, reduction in efficiency usage, shortage of energy and labour and also health risks posed to consumers as well as farmers. It is projected that the stagnant rice yield and intensified rice production in many Asian countries will cause considerable damage to the natural resources and environment including salinity and alkalinity build-up, soil and water contamination, health hazards due to excessive use of agricultural chemicals and greenhouse gas emissions with the increment of genetic erosions in rice production [5]. In regards to this, a greener and environmentally friendly farm practices should be taken into considerations to fulfil the rice demand and achieve a higher yield of paddy.

Moreover, it was reported that non-granary paddy fields in Sungai Balang, Johor is facing acidic waterways due to leaching of chemical fertilizers applied by nearby oil palm plantation and neighbouring paddy fields. Consequently, this leads to acidic soil conditions which needs to be ameliorated before paddy cultivation. Additionally, the oil palm industry generates a huge amount of oil palm wastes such as palm oil mill effluent (POME), oil palm trunk (OPT) and empty fruit bunch (EFB). These agricultural wastes are often being disposed in landfill or incinerated which is harmful to the environment as it emits greenhouse gasses (GHG). Due to its high nutrient content, the biomass wastes can be transformed into value-added products such as organic fertilizer and soil amendment. However, the lignocellulosic compounds must be broken down for easier soil absorption. The most common method to convert biomass wastes into organic fertilizer is called composting. However, it releases odour emissions and takes up to six months for the compost to fully mature. Therefore, this study investigates the potential of using subcritical water (SCW) pre-treated empty fruit bunch to improve paddy soil conditions.

2. Literature Review

2.1 Paddy Industry in Malaysia

2.1.1 Self-sufficiency level (SSL)

Self-sufficiency is the country's ability to meet its consumption needs from its own production rather than importing or buying from other countries. It can be measured using the SSL ratio where the total domestic production is divided by the total available supply, measured in percentage.

$$SSL = \frac{Production}{(Production + Import - Export)} \times 100 \quad (1)$$

The purpose of this measurement is often for a country's political interests and national security which defines its ability to provide staple food for its citizens without relying or being dependent on other countries. In Asia, the self-sufficiency level is used to indicate food security and the basis for policy design of the country. Unfortunately, relative to other SEA countries, the rice SSL of Malaysia is among the lowest and has shown a constant trend from the year 2000 until 2016 with an average SSL value of 70 %, compared to Thailand and Vietnam which has an average values of SSL at 196 % and 124 % respectively, as shown in Figure 1 [5].

Despite the land area for paddy farming has remained the same for the past years, Malaysia's paddy productivity is slow-moving which only accounts to around 70 % of its overall rice consumption. Therefore, the government's agricultural industry has made the call for a dire need to achieve the target of 100 % rice self-sufficiency level in the Eleventh Malaysian Plan (2016 – 2020). Various strategies have been designed and introduced in order to increase paddy production and achieve the self- sufficiency target [7]. However, local studies have shown that the scenario of Malaysia to reach 100 % rice SSL is unlikely. The study came into conclusion that the supply of local rice will experience a declining amount which can only be counteracted by the increase of rice imports.

In a more realistic approach, the Agriculture and Food Industries Minister, Datuk Seri Ronald Kiandee stated that the government aims to raise paddy production up to 75 % to meet the national rice consumption. This is to ensure that the country is able to sustain its rice supply and become more prepared to face situations that may affect the supply of the staple grain. Several efforts to boost and enhance the paddy production in existing paddy fields need to be done, such as identifying the right fertilizers and conducting soil profiling.

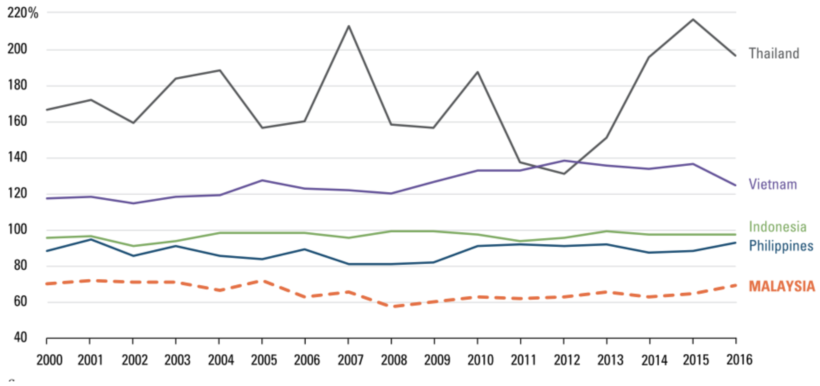

Fig. 1. SSL in the Southeast Asian region in percentage, 2000 – 2016

2.1.2 Rice production and consumption

On average, Malaysian spend RM 44 per month per household on rice, taking into account that a person consumes 80 kg of rice in a year, which is about 26 % of the total caloric intake per day. Among all the states in Malaysia, Perlis spent the least while Sabah spent the most on rice at RM 13/month and RM 73/month respectively. With a total population of approximately 31 million people, the rice consumption of Malaysia in 2016 was 2.7 million MT, where 1.8 million MT or 70 % of the total rice consumed was locally produced by paddy farmers, as shown in Table 1. However, the remaining 900,000 MT or 30 % of the total rice consumed is imported primarily from neighbouring rice importing countries such as Thailand and Vietnam. Furthermore, as the national population grows annually, Malaysia's production and consumption of rice is projected to have a widening gap in the upcoming years as reported by the OECD-FAO Agricultural Outlook. The widening gap happens as the harvested paddy area remains near constant whilst the yield per hectare increases at a slower rate than the consumption growth. This deficiency of rice supply and increase of rice demand will be encountered by an increase in the imports of rice from exporting countries [5].

One of the possible reasons that determines if the SEA country is a rice exporting or importing countries is the geographical factors. The eight SEA countries can be categorized into two distinct group which are rice importers which are Indonesia, the Philippines and Malaysia and the rice exporters which include Thailand, Vietnam, Myanmar, Laos and Cambodia. A study shows that there is a correlation between the rice exporting countries having a suitable geographical location for rice cultivation which leads to the country having a larger paddy farming area. As shown in Figure 2, the rice exporting countries such as Thailand and Vietnam are located on the mainland which has excess to large amount of fresh water from dominant rivers, cheaper labour and the availability of large area of flat lands. This contributes to the ability for large quantity of paddy production as well as lower cost of production per hectare.

Table 1
Rice production, consumption, area harvested and yield for the SEA countries

Country	Production (m MT)	Consumption (m MT)	Area Harvested (000' Ha)	Rice Yield (MT/Ha)	SSL (%)
Thailand	21.6	13.6	10,780	2.0	196
Vietnam	28.1	22.1	7,743	3.6	124
Indonesia	45.6	46.7	13,870	3.3	97
Philipines	12.1	13.5	4,722	2.6	93
Malaysia	1.8	2.7	700	2.5	70

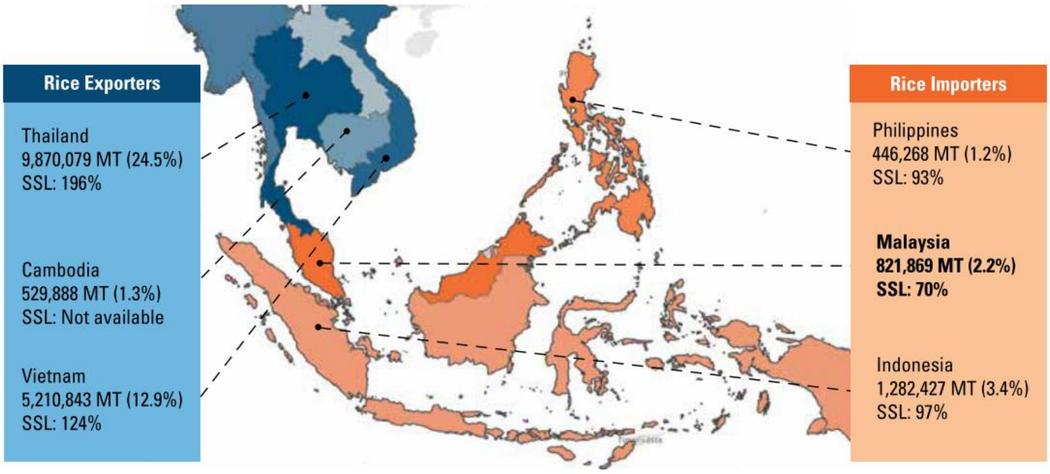

Fig. 2. Quantity and shares of the SEA rice countries, and self-sufficiency level export/import

On the contrary, the rice importing countries such as Indonesia, the Philippines and Malaysia consist of several islands or peninsular, which leads to limitations on fresh water and restrictions of large areas of flat lands. Despite the relative disadvantage of Malaysia's geographical factors compared to the mainland SEA countries, a realistic target to increase paddy production can be achieved by adhering to good agricultural practices. The government has spent billions of ringgits on building hard and soft infrastructures for paddy cultivation [5]. Furthermore, due to the location of Malaysia which is located in the equator, a large amount of rain is received as well as an easy access of paddy growing areas to large dams which aids in irrigation and water management.

2.1.3 Granary areas

In Malaysia, the allocated land for paddy cultivation is known as 'kawasan jelapang padi' or granary areas. Granary area can be defined as the areas with major irrigation more than 4000 hectares and is recognized by the government as the main paddy production area [19]. Formerly, there were eight granary areas but it has been expanded to ten granary areas. The primary ten key granary areas are where the domestic paddy production and supply is being relied upon. In 2016, a total of 2.7 million MT of paddy was produced locally, where 74.1 % or 2 million MT of the total paddy production was produced from the granary areas. The largest granary area which produces the highest production of paddy is Muda Agricultural Development Authority (MADA) which is located in the northern peninsular of Malaysia. Also known as the *'rice bowl'* of Malaysia, MADA produces 38.8 % of the national paddy production which accounts for 1.1 million MT with an average yield of 5.3 MT/Ha, as shown in Figure 3.

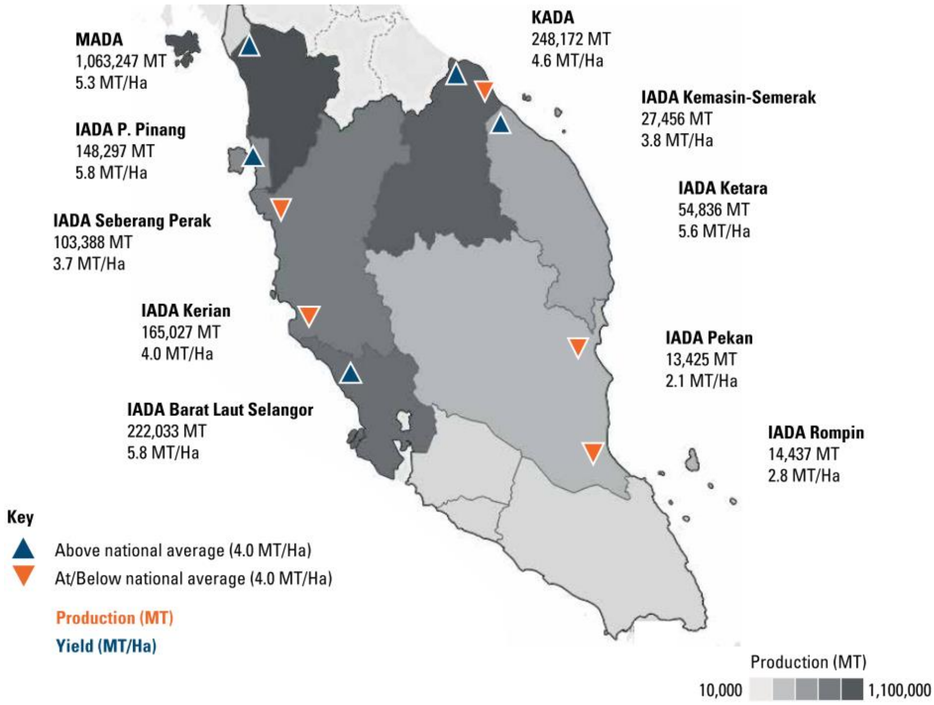

Fig. 3. Paddy production and yield in the granary areas

The national average yield of paddy is 4.0 MT/Ha. However, among the ten primary granary areas, only half of the granary areas which are MADA, IADA Barat Laut Selangor, IADA Pulau Pinang, IADA Ketara and KADA surpassed the national average yield per hectare with a value of 5.3 MT/Ha, 5.8.

The other five granary area which are IADA Seberang Perak, IADA Kerian, IADA Rompin, IADA Pekan and IADA Kemasin-Semarak have lower than the national average yield per hectare with a value of 3.7 MT/Ha, 4.0 MT/Ha, 2.8 MT/Ha, 2.1 MT/Ha and 3.8 MT/Ha respectively, as shown in Table 2 [5]. The differences in the average yield per hectare among the ten granary areas are due to the differences of their locations which means it differs in environmental conditions such as soil fertility, weather, water and irrigation systems, as well as farming practices. In order to enable Malaysia to be fully dependent and to feed the whole population from its own paddy production, the paddy production of each granary areas need to be maintained as high as 10 MT/Ha for each season [1].

Table 2
Paddy production and yield by granary areas

Granary Area	State	Paddy Production		Paddy Yield
		(%)	(MT)	(MT/Ha)
MADA	Kedah	38.8	1,063,247	5.3
Non- granary	-	24.8	679,288	-
KADA	Kelantan	9.1	248,172	4.6
IADA BLS	Selangor	8.1	222,033	5.8
IADA Kerian	Perak	6.0	165,027	4.0
IADA Pulau Pinang	Pulau Pinang	5.4	148,297	5.8
IADA Sebarang Perak	Perak	3.8	103,388	3.7
IADA Ketara	Terengganu	2.0	54,836	5.6
IADA Kemasin Semarak	Kelantan	1.0	27,456	3.8
IADA Rompin	Pahang	0.5	14,437	2.8
IADA Pekan	Pahang	0.5	13,425	2.1
Total	-	100	2,739,606	-
Average	-	-	273,960	4.35

2.1.4 Non-granary areas

Apart from the primary granary areas, there are another 74 secondary and 172 minor granary areas in Malaysia with a total of approximately 28,441 and 47,653 hectares of paddy cultivation area, respectively and eighty percent of these areas are located in Peninsular Malaysia [7]. Secondary and small granaries are classified based on the scale of irrigation supported. Together with the main granaries, they constitute about 85 % of total paddy cultivated areas. The balance of another 15 % stand for the non-irrigated areas, which include rain fed paddy fields and hill or upland paddy, which are mainly concentrated in Sabah and Sarawak. In these areas, single cropped paddy cultivation is widely practiced with little or no inputs.

Typically, the average yields in the granary areas are higher than in the non-granary areas (4.9 MT/Ha as compared to 4.0 MT/Ha in 2016). These differences can be attributed to many combinations of factors, including soil condition, weather, farm management, irrigation, pests and diseases and use of technology. In fact, in agriculture, acquiring optimal yield requires good farm management practices that have been modified to best suit the unique local conditions [5].

2.2 Problems Faced by Paddy Producers
2.2.1 Climate change

Paddy production is affected by various factors, including environmental changes due to climate change. Crop production, food prices and the reliance on food air import of many countries around the world, especially the economically vulnerable countries are impacted by the climate change. The direct impact of climate change on agriculture are classified in the increase of food security, decrease of agricultural productivity and the disruption in supply chain of production. Due to the changes in the climate and weather events, crop productivity will be altered. It is expected that by the year 2030, the paddy yield in SEA, Central America and Brazil will face a declination of paddy yield of up to 5 %.

Furthermore, it is also projected that the Peninsular Malaysia will face unfavorable climate conditions in the future as a rising trend in temperature and precipitation have been shown in every decade [7]. According to an integrated assessment model by Umesha *et al*., [22], the rice production in East Asia may be reduced by 50 % by the year 2100 due to the extreme weather patterns in the region. The International Food Policy Research Institute stated that the impact of climate change could also affect the paddy productivity throughout Asia and the Pacific. The consequences of this situation will locate millions of people in Asia to face food insecurity due to the low supply and increasing prices of crops. The increase in food prices will impact on the utilization of the poor and accessibility of food, which leads to approximately 38 million people in Asia and the Pacific into hunger.

2.2.2 Resource scarcity

Due to competition for urbanization, industrialization and residential areas expansion, the land which is available for agriculture is becoming limited. Therefore, there is a need to maximize land productivity. In Malaysia, the agriculture sector contributed only 8.9 % of the Malaysia's Gross Domestic Product (GDP). Within the agriculture sector, palm oil contributed the highest percentage which is 40.2 %, while paddy only contributed 2.3 %. This can be seen over the years from 1961 to 2016, where the total oil palm harvested area has significantly increased from 0 to 5 million hectares, while the total paddy harvested area remained relatively constant at approximately 700,000 hectares. Therefore, it is very unlikely to maintain the self-sufficiency level of rice production at 70 %

when there is an increasing demand from the growing population if the paddy productivity is not significantly increased in the future [5].

2.2.3 Water contamination

Agricultural soils contaminated with cadmium (Cd) and arsenic (As) poses a risk to receiving surface water *via* drainage or runoff. A study by Xiao *et al*., [23], proved that dissolved Cd concentrations in overlying water of the fertilizer treatment under flooding of NPK fertilizer with continuous flooding and drying- wetting were much higher than that from the corresponding controls without NPK fertilizer addition. Moreover, significant negative correlation with nearby water pH results from high Cd concentration [23]. The main anthropogenic sources of Cd are activities including wastewater irrigation and applications of chemical fertilizers and pesticides which leads to high level of Cd accumulation in soils. Due to its high toxicity and mobility, Cd contamination in agricultural soils poses health risks to human and contaminate groundwater and surface water *via* infiltration and runoff. This also leads to detrimental impacts on aquatic organisms.

2.2.4 Heavy metals

Heavy metals, even at a very low concentration are environmental pollutants that can be toxic and hazardous to plants, animals and human health. It is sourced mainly from human activities or known as anthropogenic sources that are related with agricultural and industrialization activities such as exhaust from vehicles, waste incineration, waste disposal, construction, mining and fertilizer applications [17]. Heavy metals are generally present in agricultural soils at low levels. However, due to the rapid growth in population which has increased the demand for rice consumption, paddy fields are likely to receive a significant number of anthropogenic pollutants as excessive chemical fertilizers and pesticides are applied for a greater yield profitability. This lead to heavy metals to accumulate significantly in the paddy soil [2]. There is a growing concern over heavy metals accumulation in paddy soil due to its damaging effects on soil ecosystems and potential health risks it brings to farmers and rice consumers. Large amount of water that may contain high concentration of heavy metals are supplied to the crops, which is a concern to many researchers. Furthermore, chemical fertilizers including compound and urea fertilizers applied by farmers has contributed to an increase of heavy metals contamination in paddy soil and water. High concentrations of heavy metals in the soil would increase the potential uptake of these metals by plants [2].

2.2.5 Acidic soil

Malaysia has tropical soil which is mostly a problem soil such as sandy soil, peat and acid sulphate soil. To maximize yields, these types of soil typically require special management. Malaysia has more than 0.5 million ha of acid sulphate soil scattered over the country, including Sabah and Sarawak. Acid sulphate soil are usually not suitable for crop production. These soils are characterized by lower than pH 3.5 and the presence of yellowish jarosite produced from pyrite exposed to atmosphere.

In acidic soil condition, excess hydrogen ions (H+) increase the solubility of Al, Mn and Fe in acid soils. The major plant nutrients required such as nitrogen, phosphorus and potassium are reduced which causes deficiency of nutrient availability. Due to lower availability of nutrients, the growth of roots will be poorly developed. Hence, when root growth is restricted, plants are unable to explore sufficient soil volume to compensate for the reduced chemical availability. The presence of hydrogen ions in the growth medium generally inhibits root elongation. In this case, more nutrients than should be necessary would be required for optimal plant growth. Therefore, when acidity of soil is high, farmers would require higher amount of fertilizer to compensate for the inefficiency of plant nutrients uptake thus, increasing the cost of paddy production.

2.3 Biomass Waste in Malaysia

Malaysia generates approximately 168 MT of biomass wastes annually with palm oil wastes accounting the highest percentage at 85.5 %, followed by municipal solid waste at 9.5 %, wood industry at 3.7 %, and small percentages are from sugarcane and rice industry [16]. Annually, the amount of agricultural waste produced globally is 998 MT and in Malaysia, as much as 1.2 MT of agricultural waste is disposed into landfills, with approximately 0.122 kg/cap/day are generated in 2009 and is estimated to increase to 0.210 kg/cap/day by 2025 [12]. Due to low commercial value, these wastes are disposed in landfill, which if not managed properly may cause environmental problems [20].

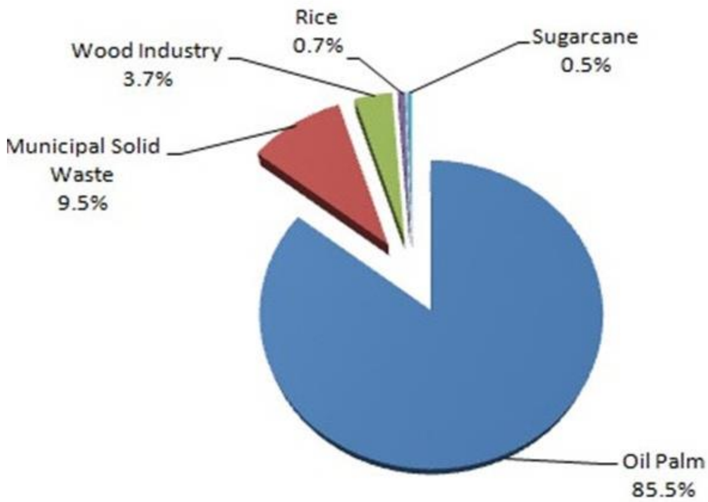

Fig. 4. Biomass waste distribution in Malaysia

Furthermore, Malaysia is one of the major producers and exporters of palm oil in the world. Throughout the years, there is advancement and development of the oil palm plantations and palm oil mills. Consequently, as the oil palm industries grow rapidly, environmental issues and concerns has been brought up as significant amount of oil palm wastes are generated every year. In 2016, around 5.74 million hectares of land areas are occupied for oil palm planting throughout Malaysia. Fresh fruit bunches (FFBs) harvested in 2017 constitutes a total of around 11.09 tons per hectares which were processed in palm oil mills.

From the harvesting of oil palm fruits, oil palm extraction process and replantation of the trees, there is a large amount of biomass or by-product residues generated. The oil palm residues are palm oil mill effluent (POME), oil palm leaves (OPL), oil palm fronds (OPF), oil palm trunks (OPT), palm kernel shell (PKS), mesocarp fiber (MF) and empty fruit bunch (EFB). Therefore, there is a large potential seen for the oil palm biomass wastes to be transformed into value-added products which can be used in many applications. The urge to convert oil palm biomass wastes into wealth is further encouraged by the fact that only 10 % of oil are generated from the extraction process whereby as much as 90 % of the oil palm production accounts for the biomass wastes [18].

2.3.1 Empty fruit bunch (EFB)

In the oil palm mill process, the FFBs produces around 23 % of EFB per tons of FFB. From the latest available data, 18.48 tons per hectare of FFBs were harvested in 2016 compared to 15.91 tons per hectare in 2015. Thus, in 2016, as much as 4 tons per hectares of EFBs are generated. Due to the rapid growth and increase of oil palm industries throughout the years, it is estimated that there will be an increase in the oil palm wastes generated. The by-product of oil palm industry is often being poorly utilized which may leads to various problems associated with the improper disposal practices of EFB, such as lack of dumping spaces, odour emissions and hazardous methane gas released from the decomposition process. Potassium (K^+), which is one of the essential macronutrients for paddy soil was found to have rich amount in EFBs. Therefore, there is a huge benefit and high potential to recycle and utilize the nutrients of EFB which can be used to fertilize the paddy soil [14].

Table 3
Chemical characteristics and properties of EFB [14]

Element	Weight percentage (dry weight)
Ash	4.9
C	43.56
H	5.34
N	0.56
S	0.11
Cl	0.67
O (diff)	44.86
K (%DM)	3.24
HHV, dry (MJ/kg)	16.7

2.4 Methods to Convert Biomass Waste into Organic Fertilizer
2.4.1 Composting

Composting is the conventional method to convert organic or biomass wastes such as agricultural and forest residues, food wastes, municipal solid wastes and animal manures into organic fertilizers. These organic and biodegradable compounds are broken down into a stable form of organic matters that can be used as fertilizers. It is a simple method to be implemented, apart from reducing the environmental and social costs when compared to other organic wastes disposal methods such as incineration and landfilling. Studies have proven that composting is a feasible method to convert these wastes into compost with a high fertilizer value. The quality and content of compost relies on the types of raw materials used, decomposition process conditions, process of composting and the additional nutrients added during the composting process.

Converting organic wastes to composts and utilizing it as fertilizers to enhance soil fertility and crop productivity helps to reduce the carbon footprint and enhances soil organic matters' management. A study shows composting is capable of reducing up to 27 % of GHG emissions compared to open dumping or landfilling. This proves composting is a more sustainable and cleaner method compared to open dumping which reuses the organic wastes to produce fertilizers for agricultural purposes [10]. However, there are several drawbacks of composting method which includes a long period of time that may takes up to three to four months for a small-scale operation, odour emissions and possible soil acidification [10].

2.4.2 Hydrolysis

Hydrolysis, or also known as saccharification is the process of converting cellulose and hemicellulose into their monomers or fermentable sugars. This can either be achieved by the biochemical route (enzymtic hydrolysis) or by the thermochemical route (acid hydrolysis), both of which requires prior pre-treatment step to efficiently utilize the lignocellulosic biomass [18].

2.4.3 Enzymatic hydrolysis

Enzymatic hydrolysis is a process where pre-treated lignocellulosic biomass is hydrolyzed into fermentable sugars by using enzyme as the catalyst. The overall rate of process is affected by the structure of lignocellulosic biomass and the source and composition of the cellulases. The hydrolysis rate is influenced mostly by the crystallinity and amount of accessible surface area of the cellulose. A cellulose fiber consists of amorphous and crystalline regions. The hydrolysis rate and yield are 100 times higher when the cellulase binds to amorphous cellulose, compared to the crystalline cellulose. The internal surface area is influenced by the plant cell wall anatomical structure and the method of pre-treatment. On the other hand, the external surface area is affected by the size and shape of the cellulosic particles. Moreover, the rate of enzymatic hydrolysis is also affected by the percentage of enzyme components and the enzyme sources [6].

2.4.4 Acid hydrolysis

In acid hydrolysis process, the acid breaks the fiber structure of lignocellulosic biomass into polysaccharides which is cellulose, hemicellulose and lignin components. Then, it is further reduced into monosaccharides or individual sugar molecules. There are two types of acid hydrolysis which are dilute acid and concentrated acid hydrolysis, where the former occurs at higher temperature than the latter [8]. The most common catalyst used for acid hydrolysis is sulphuric acid and hydrochloric acid. One of the benefits of acid hydrolysis is pre-treatment step is not required as acid can penetrate lignin, hence, the rate of acid hydrolysis is faster than enzyme hydrolysis. However, under acidic conditions, it is possible that glucose degrade rapidly [9].

2.4.5 Subcritical water (SCW)

SCW, also known as superheated water or pressurized hot water is a state where water is maintained at liquid phase between its boiling point at 100°C and its critical point at 374°C, under sufficient pressure. Water at a condition proximate to its critical point differs in properties. Among them are high solubility of organic substances and low viscosity, which makes it an excellent medium for homogenous, quick and efficient reactions. Thus, there has been an increase in interest of SCW treatment to be used as a solvent and reaction medium for biomass conversion [21].

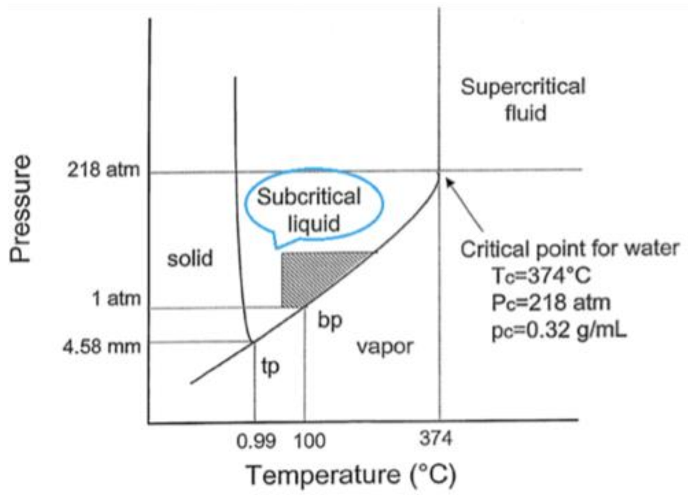

Fig. 5. Phase diagram of water as function of temperature and pressure

2.4.5.1 SCW treatment

SCW treatment has gained prominence due to its ability to recover considerable quantity of extractable components from diverse biomass. Apart from that, it is also a pre-treatment method which are inexpensive, uses non-toxic water as solvent, requires a short extraction time, has good selectivity and is an eco-friendly technology. At certain temperatures, the physicochemical of water is altered. The unique properties of water at SCW conditions are due to the high boiling point being disproportionate with its mass, high polarity and high dielectric constant. As the temperature increase, the diffusion rate increase, meanwhile the viscosity and surface tension decreases. Consequently, material with more polar target with high solubility in water at ambient conditions are extracted most efficiently at lower temperatures. However, non-polar and moderately polar targets require less polar medium induced by increase in temperature. Based on previous studies, SCW has been shown to be a faster, cleaner and cheaper extraction method compared with conventional methods [4]. SCW treatment, or hydrothermal treatment involve the breakdown of chemical and physical structure in biomass materials such as cellulose, hemicellulose and lignin into smaller and simpler molecules.

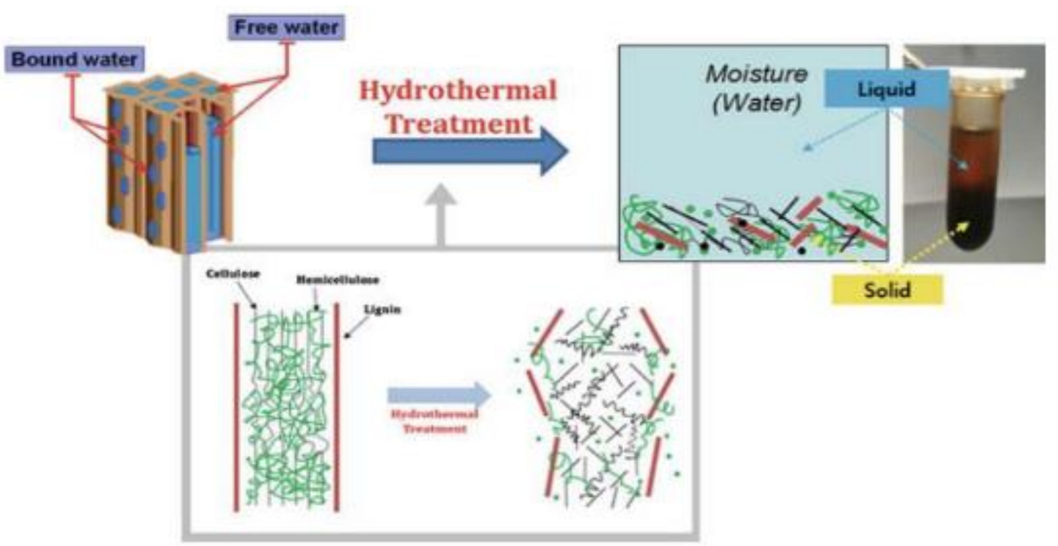

Fig. 6. Physical structure change of biomass by SCW treatment

2.5 Comparison between Conversion Methods of Biomass Wastes

The main objective of this work was to study the effect of organic fertilizer on acidic paddy soil. For that, two experimental-based studies were conducted which is lab-scale and agriculture scale. It involved oil palm EFB collection, paddy field monitoring, SCW pre-treatment, soil treatment application and data analysis. All the materials, chemicals and equipment used in this research are described in details. The below Table 4 lists the comparison between conversion methods.

Table 4
Comparison between conversion methods

Conversion method	SCW treatment	Composting	Enzymatic hydrolysis	Acid hydrolysis
Solvent/Catalyst used	Water	No-solvent	Enzymes	Protic acid
Cost	Cheap solvent	Low cost	High price of enzymes	Low cost of acid
Reaction time	30-90 mins	3-6 months	5-12 hours	~ 2 hours
Reaction condition	Temperature : 100-374˚C Pressure: 1-220 bar	Temperature : ambient Pressure : ambient	Temperature: 40-50˚C Pressure : ambient	Temperature: 100-240˚C Pressure : ambient
Benefits	Environmentally friendly. Complete disinfection of waste. Increase nutritional values	Easy and simple process	High yields of sugar. Does not corrode equipment	High reaction rates. Shorter extraction time
Drawbacks	Thermal degradation at elevated temperature	Odour pollution. Pathogen production. Possible heavy metal contamination. Occupy large land area	High consumption of enzymes. Long incubation time. Inhibition of lignin and glucose	Corrosion of process equipment. Possible formation of inhibitory compounds

3. Methodology
3.1 Process Flow of Experimental Study

To achieve the objectives of this study, two separate methodologies are shown in Figure 7. Two experimental studies were conducted which are lab-scale and agriculture-scale. The experimental study was conducted to study the effect of SCW-treated EFB on acidic soil. Firstly, to produce the SCW-treated EFB, oil palm empty fruit bunch were collected and shredded. Then, it was pre-treated using SCW technology. To study the effect of organic fertilizer on acidic soil, paddy conditions in Sungai Balang, Johor was analyzed and results were recorded. For lab-scale study, the pH value was used to replicate the acidic conditions in a pot. Four different treatments (control, chemical, raw EFB and SCW-treated EFB) were applied in the pots and results were compared. For agriculture-scale, organic fertilizer was applied in the paddy field. Then, the effects on soil pH were observed over 48 days of treatment.

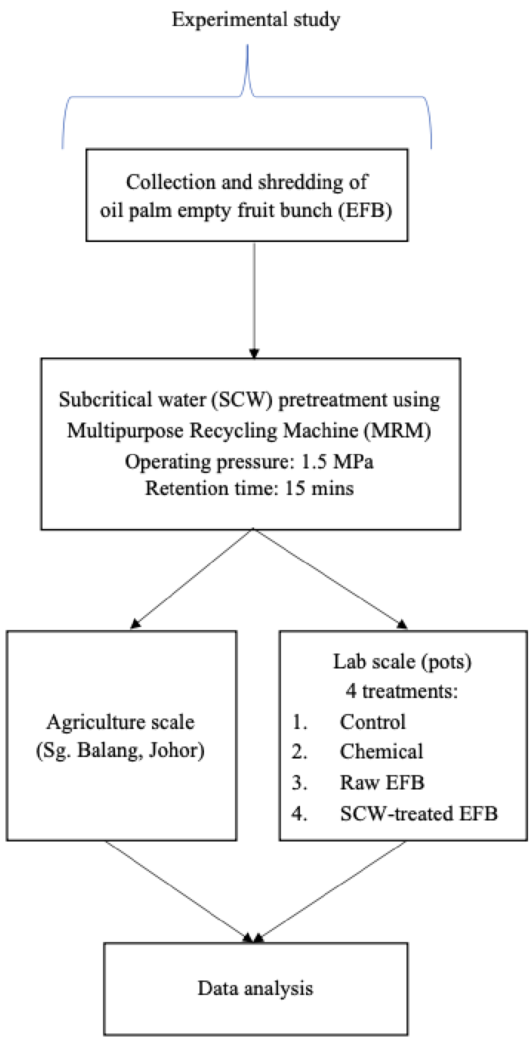

Fig. 7. Process flow of research

3.1.1 Materials
3.1.1.1 Collection of oil palm EFB

For organic fertilizer production, oil palm EFB was collected from Pagoh Palm Oil Mill which has an oil palm plantation in Muar, Johor (GPS Coordinate 2°4’40.62’’N, 102°43’7.3’’E). The oil palm EFB was received in shredded form and stored on flat ground, outdoors. The EFB were left susceptible to rain and heat from the sun.

Fig. 8. Shredded oil palm EFB

3.1.2 SCW pre-treatment

For SCW pre-treatment, a pilot scale Multipurpose Recycling Machine (MRM) with maximum volume of 2 m^3 was used as shown in Figure 9. The machine operates at a temperature between 100–200°C and can withstand pressure between 1-2 MPa. There is a screw-like stirrer located in the middle of the machine to ensure the feed were filled and processed uniformly. The control panel is located next to the MRM where parameters such as temperature and retention time can be controlled and recorded. Apart from the digital readings at control panel, pressure and temperature gauge is also installed at the MRM. The MRM has a feed inlet valve at the top and a product outlet valve at the bottom. Steam was supplied *via* boiler.

Throughout the process, all safety precautions were taken. Before the raw materials were fed into the MRM, the bottom outlet valve was ensured to be closed and the stirrer was turned on. 500 kg of shredded oil palm EFB was put in a metal trolley. A lifting hoist was used to carry the metal trolley to the top feed inlet. The shredded oil palm EFB was then poured into the feed inlet valve. The operating condition was set at 1.5 MPa and a retention time of 15 mins. From previous study, this operating condition was sufficient to break the structure and degrade the lignocellulosic components of EFB. The nutrient content and C/N ratio were also seen to be suitable to be used as organic fertilizer.

To provide subcritical conditions, all valves were ensured to be fully closed, hence the MRM was in a closed-system. Boiler was turned on and steam, generated. To ensure a consistent flow of steam into the MRM, a discharge valve was opened and flow of steam was observed beforehand. The steam was released into the MRM when the flow of steam was seen to be smooth and consistent. As the steam fill into the MRM, pressure starts to build up and temperature starts to rise. The steam inlet valve was closed as soon as the pressure reached 1.5 MPa. The timer at control panel automatically starts and SCW condition run for 15 mins.

After completing the process, steam will be gradually released through a discharge valve, thus the temperature and pressure inside the MRM decreased. When the temperature was significantly reduced, the bottom outlet valve is opened and pre-treated EFB flows into a storage cart. To separate the liquid and solid product, the cart has a built-in filter where the liquid can flow through holes and solid remains on top. The product is mainly in solid form. To study the effects on acidic soil, an amount of solid pre-treated EFB was stored in sealed gunny sacks which was later be used as soil treatment and organic fertilizer in the study.

Fig. 9. 2 m^3 Multipurpose recycling machine (MRM)

Fig. 10. Pre-treated oil palm EFB in solid form

3.1.3 Monitoring of paddy fields in Sungai Balang, Johor

The non-granary paddy area monitored in this study is located in Sungai Balang, Johor (GPS Coordinate 1°53’31.179”, 102°44’45.824”). The location was chosen as it was reported to face acidic waterways due to excessive use of chemical fertilizer at nearby paddy fields and oil palm plantation. The acidic waterways were irrigated into the paddy field which causes the paddy soil to become acidic. In this study, the paddy field analyzed was labelled as Plot C and is owned by a local paddy farmer. It consists of 6 plots with a size of 1.5 acre per plot. The total paddy area is 9 acres as shown in Figure 11.

For lab-scale study, only the pH of main waterways was used as a reference to conduct the study. It was observed that the main waterway has a pH value of 4.0. Therefore, for lab-scale study, pH 4.0 was applied to dilute the acid in order to replicate the acidic soil condition in a pot. The pot of acidic soil then was treated with different soil treatments. For the agriculture-scale study, the soil pH value was taken randomly from 3 points. The soil conditions were monitored during the 1st, 2nd and then 21 days, 32 days and 48 days after 2nd application.

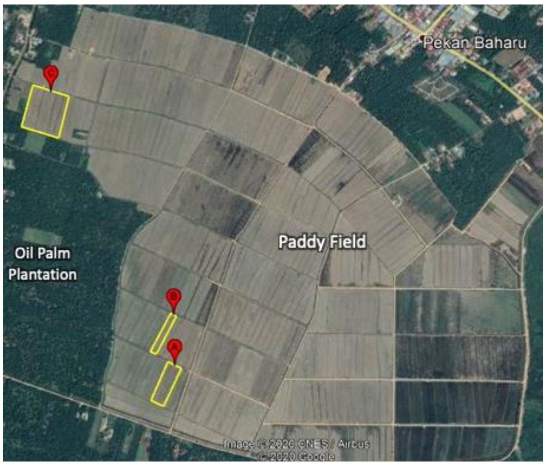

Fig. 11. Location of Plot C in Sungai Balang, Johor

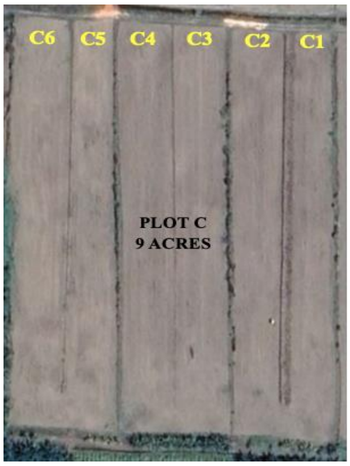

Fig. 12. Size of Plot C

3.1.4. Lab-scale study

3.1.4.1 Chemicals and standards

Glacial acetic acid, 99.7 % (R & M Chemicals brand) was used to prepare acidic solution in the lab-scale study. The purpose was to increase pH of water.

3.1.4.2 Preparation of acidic soil

Based on the monitoring of paddy conditions in Sungai Balang, the pH value of acidic waterways was pH 4.0. To replicate the acidic conditions, dilution of acid was conducted. To prepare the acidic solution, acetic acid was chosen because it is among the weak acid. 1 mL of 99.7 % acetic acid was diluted in 15 L of tap water. The dilution of acetic acid in tap water results in reduction of pH from 8.0-4.0. Diluted acid is stored in a 45 L container and labelled before being poured into pots of soil.

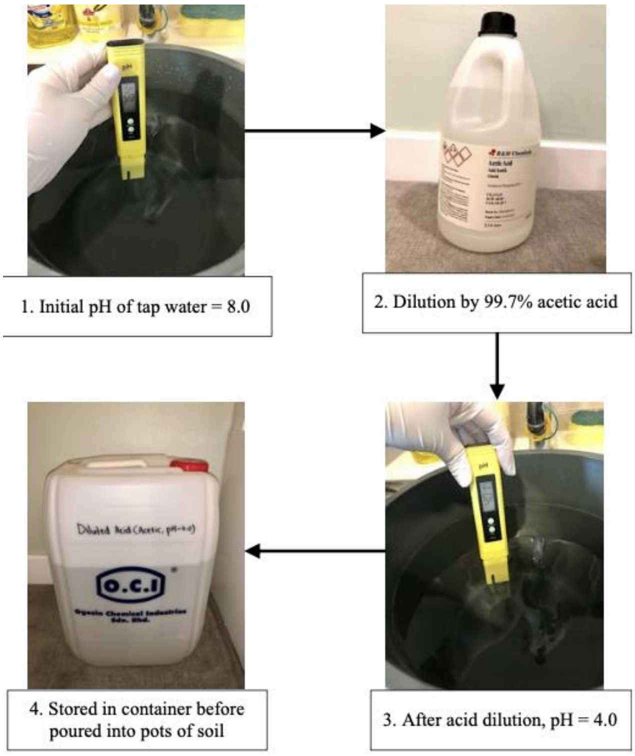

Fig. 13. Flow of acidic solution preparation

To avoid overflow of acidic solution in the pot, a size of 5 L pots were used. Each pot was treated with different soil treatments hence, the pots were labelled accordingly. To prepare the soil, 2.1 kg of potting soil mix were weighed and put into the pots. Initial pH of soil was recorded using pH meter. Then, the acidic solution was poured into each pots respectively. The level of acidic solution was maintained at 3 – 5 cm above the soil to ensure soil was fully submerged. The pH of soil was promptly recorded after acidic solution was poured.

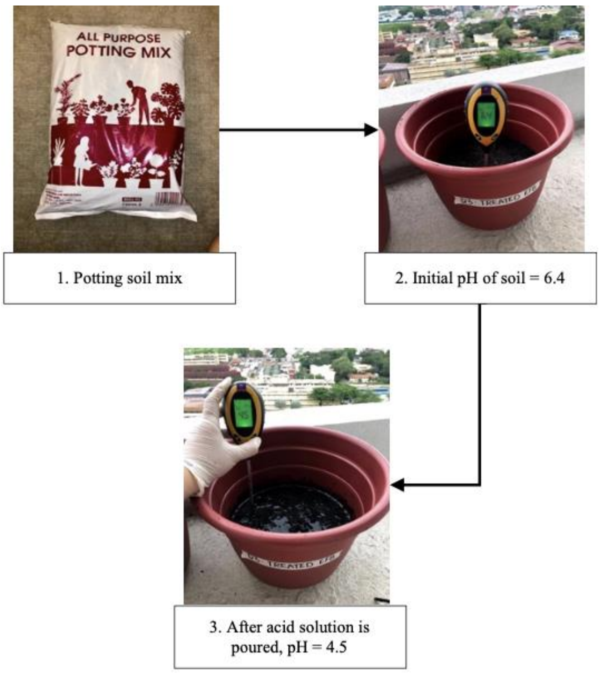

Fig. 14. Flow of acidic soil preparation

3.1.4.3 Application of soil treatments

Four types of soil treatments including control (no fertilizer), chemical fertilizer (NPK: 15-15-15), raw EFB and SCW-treated EFB were applied in pots containing acidic soil which were formerly prepared. Each soil treatments were weighed according to the Table 5. After being applied, the soil pH was immediately recorded. Control treatment where no fertilizers was applied and carried out to minimize the effects of factors other than the type of soil treatment. For chemical treatment, the amount of chemical fertilizers applied was according to the recommendations written on the commercialized packaging. To observe the significance of SCW technology, treatment: soil ratio of raw EFB and SCW-treated EFB were set at the same value. The ratio was selected based on previous findings that found the best growth effects on chili plants. All four pots were located outdoors, being susceptible to rain and heat from the sun. An average of 4 – 6 hours of direct sunlight was received.

Table 5
Independent variables to study the effect of soil treatments on soil

Independent variable	Controlled (A)	Chemical (B)	Raw EFB (C)	SCW-treated EFB (D)
Soil (g)	2100	2100	2100	2100
Treatment (g)	0	100	700	700
Total mass (g)	2100	2200	2800	2800
Ratio (treatment:soil)	-	1:21	1:3	1:3

Fig. 15. Flow of soil treatment (chemical) application in acidic soil

3.1.4.4 pH analysis

Initial pH of tap water was recorded using a digital liquid pH meter. Before using the apparatus, the pH meter was calibrated in order to get accurate pH reading. Buffer solution is used to stabilize the pH to 4.0 as it is the pH value that will be used to replicate acidic conditions in Sungai Balang, Johor. pH reading before and after acid dilution were recorded. Three readings were taken and the average value is recorded.

Furthermore, initial pH of soil was taken using a digital soil pH meter. pH reading after acid solution was poured into the pots of soil were immediately recorded. In order to study the effects of different soil treatments on acidic soil condition, the pH reading of soil were recorded for every 5 days interval until 30 days of treatment. This was because the first ploughing stage for paddy land preparation is 30 days before seeding, as stated in the Malaysia Rice Check Guideline. The readings were taken at three points in each pot.

3.1.5 Agriculture-scale study

3.1.5.1 Application of organic fertilizer

For the agriculture-scale study, SCW-treated EFB were applied to paddy field at Plot C which is located in Sungai Balang, Johor. Plot C was divided into 6 smaller plots. Each plot had a size of 1.5 acre which were labelled as C1, C2, C3, C4, C5 and C6, respectively. The amount of organic fertilizers applied was 150 kg per plot and it was manually applied by hands as in Figure 16. The paddy fields were applied in two applications, where the 2nd application was 12 days after the 1st application.

Fig. 16. Manual application of organic fertilizer

3.1.5.2 Soil pH analysis

The initial soil pH of all 6 plots were recorded using Takemura soil pH meter (Figure 17). To get an average pH value, three sampling points were taken from each plot. The sampling points were taken at the two ends of the plot (most left and most right) and the middle location. To get a more accurate result, each reading was taken three times at each sampling point. To study the effects of organic fertilizer on acidic soil conditions, the soil pH was monitored on the 1st and 2nd application of organic fertilizer. Subsequently, the soil pH was monitored on 21, 32 and 48 days after the 2nd application. All results were recorded and tabulated (Figure 18).

Fig. 17. Takemura soil pH meter

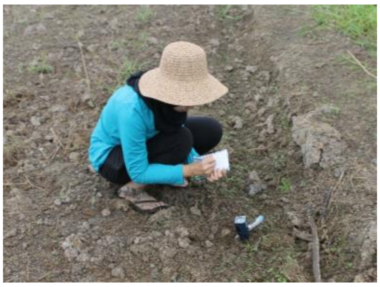

Fig. 18. Soil pH analysis at Plot C

3.1.6 Effect of soil treatment in lab-scale

Soil pH is influenced by both acid and base-forming ions in the soil. Common acid-forming cations are hydrogen (H^+), aluminum (Al^{3+}) and iron (Fe^{2+}) or (Fe^{3+}), whereas base-forming cations include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+) [11]. Typically, lower soil pH indicates a higher amount of H^+ ions, whereby higher soil pH indicate higher amount of cations such as K^+ in the soil. For paddy cultivation, the optimum pH range is between 5.5 – 6.5, with any values below pH 5.5 is considered acidic, and above 6.5 is too alkaline. Ensuring the soil pH is at an optimal range before paddy cultivation is important as it highly influences the availability and solubility of essential nutrients required for the growth of paddy plant.

In this study, the aim is to find the soil treatment which can increase pH of acidic soil and maintain the pH between 5.5 – 6.5. A replicated acidic paddy condition of Sungai Balang, Johor was conducted in pots of soil. From Table 6, initial soil pH was neutral at pH 6.0. After acidic solution (pH 4.0) was poured into the pots, pH of soil promptly decreased to pH 4.5 which indicated a need for soil treatment before paddy cultivation. Four different soil treatments were applied for 30 days to study the impact on soil acidity.

Over 30 days of treatment, all four treatments obtained different average pH of the soil. Control and chemical treatment were unable to alleviate the acidity of soil up to the optimal pH range, obtaining an average of pH 5.0 and 5.44, respectively. Raw EFB and SCW-treated EFB increased the soil acidity up to the optimal pH ranged from 6.11 and 6.23, respectively. This may be due to its high organic matter in which the soil recovers its natural buffer capacity hence, increase in pH of acidic soil can be seen. However, the average pH value could not be used to find the best soil treatment as the value may significantly fluctuate over time. Therefore, the effects of each soil treatment were individually observed and discussed in the 30 days of treatment.

Table 6
Average pH of soil over 30 days of treatment

Average pH of soil	Control (A3)	Chemical	Raw EFB (C3)	SCW-treated EFB (D3)
Initial soil pH	6.27	6.37	6.17	6.33
After acid solution	4.50	4.50	4.53	4.50
Over 30 days of treatment	5.00	5.44	6.11	6.23

For controlled treatment (A3), the soil remained acidic with highest pH obtained 2 days after treatment at pH 5.3, and the lowest pH on 20 days after treatment at pH 4.77. Without any soil treatment, the fluctuations in soil pH was influenced by the acidic solution poured into the soil and the natural rainfall which was slightly acidic due to carbon dioxide in the atmosphere [15]. In general, acidic soil reduces the availability and efficiency of nutrients uptake, and also causes poor root development of paddy plants. To compensate the reduced chemical availability, higher amount of fertilizers are needed to be applied to provide sufficient nutrients to the paddy plant.

For chemical treatment (B3), the pH of soil increases from 4.5 - 6.0 over 10 days of treatment. However, after 15 days of treatment, it substantially decreased back to acidic condition with pH below 5.5. This was attributed to nitrogen (N) fertilizers containing N in the forms of ammonium, nitrate and urea having huge influence on soil pH over time. When ammonium-based N fertilizers were applied to the soil, it reacts with water to form bicarbonate and ammonium-N. The bicarbonate then reacts with hydrogen (H^+) ions in the soil which is an alkaline reaction, hence, pH of soil temporarily rises. However, as the ammonium-N undergoes nitrification, H^+ is released and accumulated, thus, the pH of soil is reduced [7]. Therefore, the use of chemical fertilizers may initially improve soil acidity but it is not able to maintain an optimum soil pH over time. Low pH soil will influence soil bacteria and nutrient availability for the paddy plants. Therefore, the use of chemical fertilizers are not recommended in treating acidic paddy soil.

For raw EFB (C3), pH of soil immediately increased from 4.50 - 5.80 after the treatment was applied on acidic soil due to the alkaline nature of EFB at pH 7.28. However, the pH of soil start to increase significantly after 25 days of treatment up to pH 6.73, which was above the optimum pH range. As the days of treatment increases, raw EFB starts to decompose and the organic matter content in the soil increases. Decomposition of organic matter causes the total N and K to increase while soil organic C to decrease. Hence the C/N ratio of soil decreases [12]. C/N ratio is inversely proportional with pH. Therefore, as the content of organic matter in the soil increases due to decomposition of EFB, a strong effect of alkaline soil pH can be observed over time [3].

For SCW-treated EFB (D3), it is observed that soil pH immediately increased from 4.5 - 5.9 after treatment was applied to acidic soil. This was due to the alkalinity of SCW-treated EFB. Two days after treatment, pH of acidic soil increased to initial soil pH at 6.40, and maintained at an optimum range between 6.17 – 6.40 throughout the 30 days of treatment. There was no significant increase or decrease observed in soil pH. This may be due to the high cation content especially potassium (K) in SCW-treated EFB [14]. As pH rose due to the alkalinity of treated EFB, the soil CEC also increased, therefore, greater concentrations of potassium were available for the soil. This is important as availability of potassium is essential for root growth of paddy plant.

However, the operating temperature of SCW treatment is a crucial parameter to ensure pH of SCW-treated EFB does not become too acidic. This is because as operating temperature increase, decomposition occurs more severely causing more formation of organic acids thus, decreasing the pH of products formed. Low pH value of SCW-treated EFB could cause seed damage and fertilizer burn to paddy plants [13]. Thus, the operating pressure of 1.5 MPa and retention time of 15 mins was considered a feasible condition to produce SCW pre-treated EFB to be applied as soil treatment. Figure 19 depicts the summary of the abovementioned discussion.

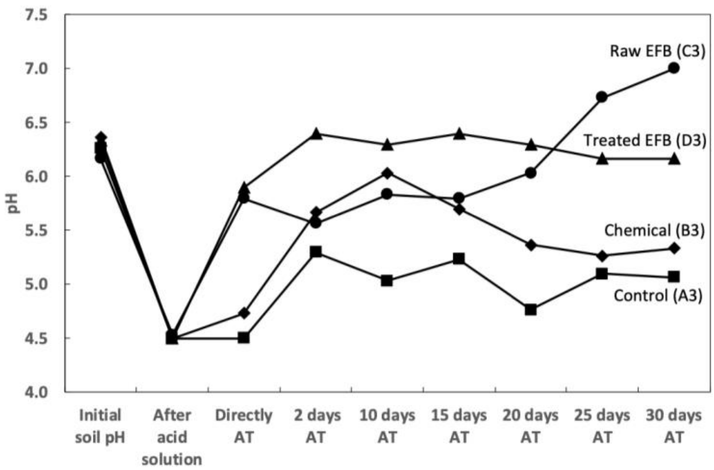

Fig. 19. Effects on soil pH before and after treatment (AT)

4.2.2 Effects of organic fertilizer in agriculture-scale

Due to the acidic waterways, acidic soil conditions were faced at Sungai Balang, Johor which needed to be ameliorated before paddy cultivation. In this agriculture-scale study, SCW-treated EFB was applied in the acidic soil of plot C and the effects on soil pH were investigated. Plot C was divided into 6 separate plots which were labelled as C1, C2, C3, C4, C5 and C6, respectively.

From the initial monitoring of paddy field, it was observed that 4 plots; C1, C2, C4 and C5 in plot C faced acidic soil condition with pH below 5.5, which is not suitable for cultivating rice. Only 2 plots, C3 and C6 were observed to have soil pH between the optimum range of 5.5 – 6.5. This may be due to the rice straw being collected and left to decompose at the respective plots during the previous cultivation season, which leads to nutrients degradation from decomposition and increase in soil pH. Thus, to prepare the land before rice cultivation, 1st application of SCW-treated EFB were applied in every plot with the same rate of 150 kg of SCW-treated EFB per plot.

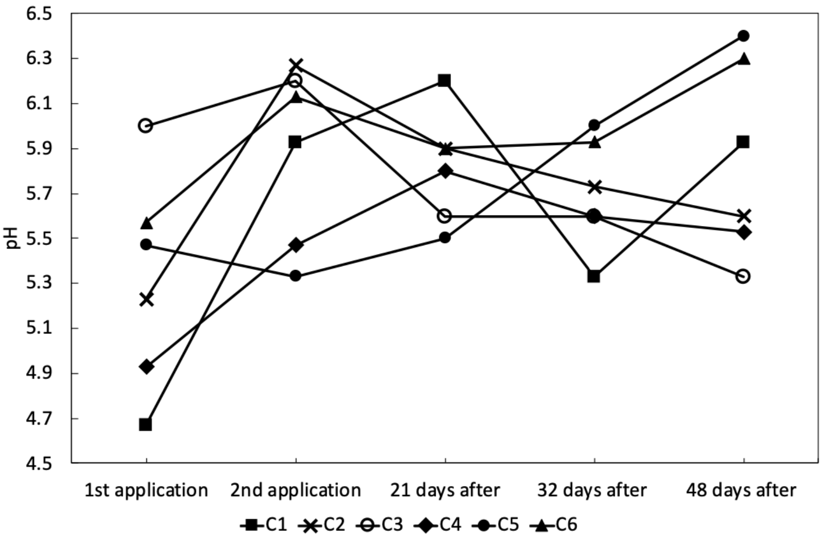

Fig. 20. Effects on soil pH from 1st application until 48 days after

The time interval between the 1st and 2nd application were 12 days. This was to ensure the organic fertilizer to fully incorporate in the soil and nutrients were well-absorbed. On the 2nd application of treatment, significant increase of pH were observed in plots C1, C2, C4 and C6. This shows the ability of SCW-treated EFB to efficiently increase soil pH after only 12 days of treatment by one application. However, plot C5 showed a slight decrease in soil pH from 5.5 - 5.33, turning slightly acidic. Plot C3 showed slight increase from 6.0 - 6.2 but still remained in the optimal pH range below 6.5.

All plots were then monitored 21, 32 and 48 days after the 2nd application of SCW-treated EFB. It was observed that after the 2nd application, the soil pH for plots C2, C3, C4, C5 and C6 had stable soil pH values, ranging from 5.5 – 6.0 and did not have any significant or drastic fluctuations after 32 days of treatment. However, plot C1 were observed to face a significant decrease of soil pH from 6.2 - 5.3 after 21 days and 32 days from 2nd application, respectively. This may be due to the proximity of plot C1 to the acidic waterways which is located right next to it. Hence, plot C1 is more affected and has higher chance to be puddled by the highly acidic waterways, especially if the land is not well-levelled.

Fourty-eight days after 2nd application of SCW-treated EFB, all plots except plot C3 obtained soil pH between 5.53 – 6.40, that is in the optimum range for paddy cultivation. From the initial 4 plots which face acidic soil conditions, all of the plots obtained an increasing soil pH up to the optimum pH range. In overall, significant results in soil pH can be seen from all plots except plot C3. The acidic soil in plot C1 were significantly improved from pH 4.67 - 5.93. Plot C2 increased from pH 5.23 - 5.60. Plot C4 improved from pH 4.93 - 5.53. Plot C5 obtained an increase in soil pH from 5.47 - 6.4. Lastly, plot C6 also improved from pH 4.93 up to 5.53. Therefore, it can be concluded that SCW-treated EFB can be used as soil amendment and organic fertilizer as it improves the acidity of paddy soil. Furthermore, due to its high nutrient contents, it can also help to reduce the amount of chemical fertilizers required for the subsequent paddy cultivation.

5. Conclusion

In conclusion, it is apparent that improving paddy cultivation methods plays a big role to ensure the national rice supply and demand gap is reduced. Due to the depletion of resources, increasing population and climate changes, the national paddy yield needs to be increased using a more sustainable farming method. By reviewing high-yielding country such as Vietnam, conventional farming methods could be changed to a better alternative which focuses on reducing farming inputs to mitigate the environmental damage, and increase the farmers' income. In order to achieve this, the key farming methods include seed and water management, on-farming machineries, fertilizer application, weed control and soil acidity should be given much attention by paddy farmers as well as the government. Thus, to help increase Malaysia's growth in paddy yield, local farmers should adopt the recommended sustainable farm practices and the national allocation towards R&D to develop more varieties, better technologies, improved farm management should be intensified.

Furthermore, it can be said that acidic paddy soil can be effectively ameliorated by applying SCW-treated EFB which can improve pH and organic matter in soil. In general, SCW-treated EFB were able to increase the acidic soil up to an optimum pH range for paddy cultivation, which is between pH 5.5 – 6.5, as stated by majority cultivation guidelines. Both lab-scale and agriculture-scale studies has proved the hypothesis of this study. In the lab-scale study, soil pH maintained between 6.1 – 6.4 over the 30 days of application. In the agriculture-scale study, SCW-treated EFB were able to improve all plots which were initially too acidic for paddy cultivation and increased the pH between 5.5 – 6.4 after 48 days of two-time applications. The ability to decrease soil acidity helps to reduce liming requirements in soil. Moreover, as it increased and maintained the soil to an optimum pH, more efficient plant nutrients uptake is possible due to the better availability and solubility of essential nutrients required for the growth of paddy plant. Thus, SCW-treated EFB can also be used as an alternative to chemical fertilizers to improve soil fertility. Root development of paddy plant was also unobstructed, hence the amount of fertilizer applied can be reduced. Therefore, by applying SCW-treated EFB as soil amendment, acidic paddy soil can be improved and a more sustainable farming practice can be implemented in order to achieve higher paddy yield with reduced chemical inputs, lower cost of paddy production and less damage to the environment.

References

[1] Adnan, Nadia, and Shahrina Md Nordin. "How COVID 19 effect Malaysian paddy industry? Adoption of green fertilizer a potential resolution." *Environment, development and sustainability* 23, no. 6 (2021): 8089-8129. https://doi.org/10.1007/s10668-020-00978-6

[2] Alrawiq, Nasser, J. Khairiah, T. M. Latif, and S. B. Ismail. "The concentration and distribution of selected heavy metals (Pb, Cd, Cu and Zn) in soils collected from the rice fields of MADA in Kedah, Malaysia." In *AIP Conference Proceedings*, vol. 1571, no. 1, pp. 576-582. American Institute of Physics, 2013.

[3] Anyaoha, Kelechi E., Ruben Sakrabani, Kumar Patchigolla, and Abdul M. Mouazen. "Critical evaluation of oil palm fresh fruit bunch solid wastes as soil amendments: Prospects and challenges." *Resources, Conservation and Recycling* 136 (2018): 399-409. https://doi.org/10.1016/j.resconrec.2018.04.022

[4] Asl, A. Haghighi, and M. Khajenoori. "Subcritical water extraction." *Mass Transfer-Advances in sustainable energy and environment oriented numerical modeling* (2013): 459-487.

[5] Omar, Sarena Che, Ashraf Shaharudin, and Siti Aiysyah Tumin. "The status of the paddy and rice industry in Malaysia." *Khazanah Research Institute. Kuala Lumpur* (2019).

[6] Fan, Z. (2014) *Consolidated Bioprocessing for Ethanol Production*. https://doi.org/10.1016/B978-0-444-59498-3.00007-5

[7] Firdaus, RB Radin, Mou Leong Tan, Siti Rahyla Rahmat, and Mahinda Senevi Gunaratne. "Paddy, rice and food security in Malaysia: A review of climate change impacts." *Cogent Social Sciences* 6, no. 1 (2020): 1818373. https://doi.org/10.1080/23311886.2020.1818373

[8] Jahnavi, Gentela, Govumoni Sai Prashanthi, Koti Sravanthi, and Linga Venkateswar Rao. "Status of availability of lignocellulosic feed stocks in India: biotechnological strategies involved in the production of bioethanol." *Renewable and Sustainable Energy Reviews* 73 (2017): 798-820. https://doi.org/10.1016/j.rser.2017.02.018

[9] Lenihan, P., Angela Orozco, Eddie O'Neill, M. N. M. Ahmad, D. W. Rooney, and G. M. Walker. "Dilute acid hydrolysis of lignocellulosic biomass." *Chemical Engineering Journal* 156, no. 2 (2010): 395-403. https://doi.org/10.1016/j.cej.2009.10.061

[10] Lim, Li Yee, Chew Tin Lee, Cassendra Phun Chien Bong, Jeng Shiun Lim, and Jiří Jaromír Klemeš. "Environmental and economic feasibility of an integrated community composting plant and organic farm in Malaysia." *Journal of environmental management* 244 (2019): 431-439. https://doi.org/10.1016/j.jenvman.2019.05.050

[11] McCauley, Ann, Clain Jones, and Jeff Jacobsen. "Soil pH and organic matter." *Nutrient management module* 8, no. 2 (2009): 1-12.

[12] Neh, A., and N. E. Ali. "Agricultural waste management system [AWMS] in Malaysian." *Open Access Journal of Waste Management & Xenobiotics* 3, no. 2 (2020): 1-2. https://doi.org/10.23880/oajwx-16000140

[13] Nguyen, Van Sinh, Hung Manh Nguyen, Anika Klotzbücher, Doris Vetterlein, Thimo Klotzbücher, Reinhold Jahn, Janina Schneiker et al. "From science to application: field demonstrations to enhance sustainable rice production in the north of Vietnam—lessons from the LEGATO project." *Paddy and Water Environment* 16 (2018): 353-358. https://doi.org/10.1007/s10333-018-0644-0

[14] Novianti, Srikandi, Anissa Nurdiawati, Ilman Nuran Zaini, Hiroaki Sumida, and Kunio Yoshikawa. "Hydrothermal treatment of palm oil empty fruit bunches: an investigation of the solid fuel and liquid organic fertilizer applications." *Biofuels*7, no. 6 (2016): 627-636. https://doi.org/10.1080/17597269.2016.1174019

[15] Nurdiawati, Anissa, Srikandi Novianti, Ilman Nuran Zaini, Bakhtiyor Nakhshinieva, Hiroaki Sumida, Fumitake Takahashi, and Kunio Yoshikawa. "Evaluation of hydrothermal treatment of empty fruit bunch for solid fuel and liquid organic fertilizer co-production." *Energy Procedia* 79 (2015): 226-232. https://doi.org/10.1016/j.egypro.2015.11.469

[16] Ozturk, Munir, Naheed Saba, Volkan Altay, Rizwan Iqbal, Khalid Rehman Hakeem, Mohammad Jawaid, and Faridah Hanum Ibrahim. "Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia." *Renewable and Sustainable Energy Reviews* 79 (2017): 1285-1302. https://doi.org/10.1016/j.rser.2017.05.111

[17] Payus, Carolyn, Aqilah Farhana Abu Talip, and TAN WEI HSIANG. "Heavy metals accumulation in paddy cultivation area of Kompipinan, Papar District, Sabah." (2015).

[18] Wijaya, Yanuar Philip, Robertus Dhimas Dhewangga Putra, Vania Tanda Widyaya, Jeong-Myeong Ha, Dong Jin Suh, and Chang Soo Kim. "Comparative study on two-step concentrated acid hydrolysis for the extraction of sugars from lignocellulosic biomass." *Bioresource technology* 164 (2014): 221-231. https://doi.org/10.1016/j.biortech.2014.04.084

[19] Rahmat, Siti Rahyla, RB Radin Firdaus, Samsurijan Mohamad Shaharudin, and Lim Yee Ling. "Leading key players and support system in Malaysian paddy production chain." *Cogent Food & Agriculture* 5, no. 1 (2019): 1708682. https://doi.org/10.1080/23311932.2019.1708682

[20] Shitu, A., S. Izhar, and T. M. Tahir. "Sub-critical water as a green solvent for production of valuable materials from agricultural waste biomass: A review of recent work." (2015): 255-264.

[21] Toor, Saqib Sohail, Lasse Rosendahl, and Andreas Rudolf. "Hydrothermal liquefaction of biomass: a review of subcritical water technologies." *Energy* 36, no. 5 (2011): 2328-2342. https://doi.org/10.1016/j.energy.2011.03.013

[22] Umesha, Sharanaiah, Honnayakanahalli MG Manukumar, and Bhadvelu Chandrasekhar. "Sustainable agriculture and food security." In *Biotechnology for sustainable agriculture*, pp. 67-92. Woodhead Publishing, 2018. https://doi.org/10.1016/B978-0-12-812160-3.00003-9

[23] Xiao, Wendan, Xuezhu Ye, Xiaoe Yang, Tingqiang Li, Shouping Zhao, and Qi Zhang. "Effects of alternating wetting and drying versus continuous flooding on chromium fate in paddy soils." *Ecotoxicology and environmental safety* 113 (2015): 439-445. https://doi.org/10.1016/j.ecoenv.2014.12.030