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Mechanization of Tillage and Harvesting Operations for Paddy Production in Malaysia: Challenges and Potentials

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Mechanization of Tillage and Harvesting Operations for Paddy Production in Malaysia: Challenges and Potentials

A SEARCA Regional Professorial Chair Lecture

by

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The *SEARCA Professorial Chair Lecture Monograph* series highlights the significant academic contributions of outstanding Southeast Asian experts in the academe who have championed inclusive and sustainable agricultural and rural development in Southeast Asia. The study areas include, but are not limited to, social sciences, marine and fishery sciences, environmental sciences, economics, and rural development-oriented fields. This monograph is published twice a year in June and December.

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Foreword

"Mechanization of Tillage and Harvesting Operations for Paddy Production in Malaysia: Challenges and Potentials" is a publication under the *SEARCA Professorial Chair Lecture Monograph* series. SEARCA began its **Professorial Chair** program in 1974 initially for highly deserving faculty members from the University of the Philippines Los Baños, SEARCA's host institution. In 2012, the Center expanded it to the **Regional SEARCA Professorial Chair** program to highlight the significant academic contributions of outstanding experts in Southeast Asia. To date, SEARCA has awarded 56 regional professorial chair grants in the fields of agriculture and related sciences.

This issue of the monograph series highlights the importance of farmers and engineers being aware of appropriate mechanization technologies to address problems on their farms. Specifically, this publication discusses the difference between conventional equipment and new machinery used for soil tillage and paddy harvesting, their performance, and their impacts on the soil condition of the paddy field. The monograph suggests that using new agricultural machinery, particularly the half-track tractor, is more efficient and economical for tillage, while the medium-sized combine harvester offers a technical advantage.

This publication is timely as it is part of the Regional SEARCA Professorial Chair grant, which the Center navigates in its **Eleventh Five-Year Plan on Accelerating Transformation through Agricultural Innovation** or **ATTAIN**. The proper use of machine technology in the paddy field can help improve paddy production, maximizing farmers' profits.

For its part, SEARCA will continue its efforts to recognize the contribution of institutions and support outstanding individuals contributing to agriculture and rural development in Southeast Asia. This *Professorial Chair Lecture Monograph* series is a testament to the contributions that would hopefully inspire others to emulate and act on.

GLENN B. GREGORIO
Center Director, SEARCA

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About the Author

Dr. Nazmi Mat Nawi, the 2020–21 SEARCA Regional Professorial Chair awardee, specializes in agricultural mechanization and postharvest engineering. Dr. Nazmi obtained his Bachelor of Engineering (biological and agricultural) from the Universiti Putra Malaysia (UPM) in 2005. Upon graduation, he worked in a palm oil mill as an assistant mill engineer for about a year. In 2007, he was granted a scholarship by the Ministry of Higher Education Malaysia to further his studies. He earned his master's degree in engineering from the University of Southern Queensland, Australia, with a major in agricultural engineering. In 2010, he started his PhD in the same university and specialized in precision agriculture for sugarcane farming.

After completing his PhD in 2014, Dr. Nazmi was appointed as a senior lecturer at the Department of Biological and Agricultural Engineering, Faculty of Engineering, UPM. Since then, he has played a key role in establishing modern mechanization system for paddy and oil palm industries in Malaysia. Due to his diligent commitment to agricultural mechanization, he was appointed as a principal researcher at the Smart Farming Technology Research Centre, UPM in 2016. In 2020, he was appointed as the head of the Laboratory of Plantation System Technology and Mechanization, Institute of Plantation Studies, UPM. In March 2020, considering his excellent contributions to UPM and to the nation, he was promoted to associate professor.

Dr. Nazmi is a prolific researcher, having been involved in 13 research projects and receiving a total research grant of MYR 2.5 million (USD 638,000). To date, Dr. Nazmi has published more than 78 scientific papers with over 307 citations. His publications focus mostly on agricultural mechanization, farm machinery, and nondestructive measurement for crops. Under his supervision, six PhD and five master's students have graduated. This extraordinary accomplishment has earned him the SEARCA Regional Professorial Chair.

In terms of professional contribution at the international level, Dr. Nazmi was appointed as a visiting scholar to Universitas Brawijaya in Indonesia (2020), Chonnam National University in South Korea (2019), Ataturk University in Turkey (2018), and National Taiwan University in Taiwan (2017). At the national level, Dr. Nazmi has actively contributed his expertise to the department, faculty, university, and country. Accordingly, he has been appointed as a member of an expert panel, as an evaluator and consultant, and as a national committee member and advisor in several government agencies, including the Malaysian Palm Oil Board, Ministry of Primary Industry, Malaysian Agricultural Research and Development Institute, National Farmers' Association, and vocational colleges under the Ministry of Education, Malaysia.

Currently, Dr. Nazmi is a graduate member of the Board of Engineers, Malaysia and of the Institute of Engineers, Malaysia. He is also a professional member of the Malaysian Society of Agricultural and Food Engineering.

Acronyms

2WD	two-wheel drive
4WD	four-wheel drive
AHRS	attitude and heading reference systems
CA	conservation agriculture
CCH	conventional combine harvester
EFC	effective field capacity
FC	fuel consumption
FCt	fuel cost
FE	field efficiency
FMI	field machine index
GNSS	Global Navigation Satellite System
HTT	steel half-tracked tractor
IADA	Integrated Agricultural Development Area
IoT	Internet of things
IR4.0	Industrial Revolution 4.0
LCH	large combine harvester
MCH	medium-sized combine harvester
NAFP	National Agro-Food Policy
PA	precision agriculture
RWT	rubber-wheeled tractor
SEA	Southeast Asia
SSL	self-sufficiency level
T1	first tillage
T2	second tillage
TFC	theoretical field capacity

Mechanization of Tillage and Harvesting Operations for Paddy Production in Malaysia: Challenges and Potentials

Nazmi Mat Nawi

ABSTRACT

Rice is a crucial food crop in Malaysia, being the staple food of the 31 million residents. However, the country's annual rice production of 1.8 million MT can fulfill only about 70 percent of the national self-sufficiency level, while the remaining 30 percent is still being imported from other countries. Over the years, the Malaysian government has introduced several strategies to enhance the efficiency, productivity, and cropping intensity of the rice industry in the country. Such initiatives include promoting the full utilization of modern mechanization and automation technologies. Many studies have shown that adopting appropriate mechanization could minimize production costs, increase the yield, and improve product quality.

Soil tillage and grain harvesting are the most energy-demanding and time-consuming operations in paddy production. As such, these two field operations have been fully mechanized in Malaysia. However, although mechanization can increase the productivity of paddy production, using heavy machines such as tractors and combine harvesters also poses challenges. For one, using such heavy machinery can cause soft soil condition and soil compaction and can damage the soil of the paddy field due to the high ground contact pressure pneumatic rubber tires of the machinery. Furthermore, using rubber tires on field machines leads to poor tractive performance and trafficability due to high slippage, thus increasing operating costs. Using a large combine harvester during the harvesting period can also cause several problems such as soil compaction, hardpan breakage, higher operational costs, higher grain losses, and limited access to a small paddy field. Moreover, a large combine harvester is difficult to transport from one place to another.

The continuing revolution in mechanization technology has led to the introduction of new machinery for soil tillage and paddy harvesting, which can potentially overcome the existing challenges in mechanized paddy production. A new crawler-type tractor, which is relatively lighter and smaller than the conventional tractor, has been introduced for tillage. This type of tractor has higher tractive performance and lower operating cost than the traditional tractor. Likewise, a new medium-sized combine harvester equipped with rubber tracks has been recently made available in the market. This machine causes minimum soil damage and has been hinted to have better field performance and lower operating cost.

However, before these newly introduced machineries can be fully adopted by the industry, their field performances should be evaluated by comparing them with those of the conventional equipment. Their impacts on the soil condition of the paddy field should also be investigated. These field measurements are important because the proper selection and management of machines are the key strategies to maximize field performance and to minimize machine operating costs. Alternatively, farmers could also adopt conservation agriculture methods.

In conclusion, this paper provides an overview of the paddy production in Malaysia and reviews the current mechanization status in paddy production in the country, especially for tillage and harvesting operations. It also reviews the challenges in using the existing machinery and the potential solutions to those problems through the latest machinery technology.

INTRODUCTION

Agriculture remains one of the important economic sectors in Malaysia. Under the National Key Economic Areas[1] of Malaysia, the agriculture sector is prioritized due to its potential to accelerate economic growth by creating more jobs and increasing farmers' income (Dardak 2015). Over the years, the agriculture sector has employed more than 1.6 million people in Malaysia (Dardak 2015). Likewise, the agriculture, forestry, and fisheries sectors contributed MYR 106.5 billion (USD 26.6 billion) to Malaysia's GDP in 2016, having an 8.9 percent share in national GDP (Omar, Shaharudin, and Tumin 2019). Within the agriculture sector, the palm oil industry made the biggest contribution of MYR 41.9 billion (40.2%) in the same year, while the paddy industry contributed only about MYR 2.4 billion (2.3%) (DOS 2018). In terms of production, the oil palm plantation subsector contributed about 102 million MT, whereas the paddy subsector contributed about 2.6 million MT. Although the contribution of the paddy industry to GDP is low, it is still a significant crop for the nation due to its complex relationship with food security, culture, and other socioeconomic factors.

Generally, the agriculture sector in Malaysia can be divided into two categories, namely, industrial crops and food crops. On one hand, industrial crops refer to the production of commodity crops (e.g., oil palm, rubber, tea, cocoa) and are normally planted by large estate companies. On the other hand, food crops refer to the production of vegetables, fruits, tubers, and grain crops, which are mostly grown by smallholders. Paddy cultivation produces one of the most important crops under the food crops category. Rice is a staple food in Malaysia, where the local production is able to provide 70 percent of its self-sufficiency level (Dilipkumar et al. 2018). Due to the deficit in supply, the country needs to import rice from other countries such as Thailand, Vietnam, and India.

In Malaysia, the importance of mechanization and automation technologies for increasing crop yield and quality has been highlighted in the 2011–20 National Agro-Food Policy (NAFP). Accordingly, one of the strategies included in the policy is to increase the efficiency of mechanization, automation, and precision agriculture technologies. Mechanization and automation are needed to perform various field operations involved in paddy cultivation. Muazu et al. (2014) claimed that mechanization in paddy cultivation—which uses an appropriate type, size, and power ratings of tools, implements, and machineries—can increase farm productivity

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1 Under Malaysia's Economic Transformation Programme, the 12 National Key Economic Areas are prioritized on public investment and policy support, being expected to make substantial contributions to Malaysia's economic performance.

as mechanization makes the use of time and labor more efficient. Furthermore, mechanization also shortens the period to complete critical farm operations, thereby helping to avoid field losses. Baruah and Bora (2008) demonstrated that human labor could be reduced by increasing the level of mechanization.

At present, only about five percent of the world's population is involved in agriculture, with most of them composed of the elderly. In Malaysia's 31.8 million population, around 43.9 percent are composed of the youth. However, only 15 percent of the youth is involved in agriculture (Lazim et al. 2020), which has consequently created a labor shortage in the sector. As such, several developed nations such as the US, Germany, and Japan have been modernizing their agriculture sector through mechanization, automation, and digitalization technologies. Integrating these technologies into paddy cultivation can reduce the dependency of the agriculture sector on labor and can also attract younger generations to engage in agriculture.

The latest Malaysian Plan (12th Malaysia Plan: 2021–25) prioritizes modernizing and transforming the agriculture sector to increase sustainable production. Aimed at improving food security and generating high and sustainable income for farmers, the plan has provisions for financial support, incentives for automation and mechanization, efficient marketing channel, capacity building, and infrastructure (EPU 2021).

Several national initiatives have been implemented to enhance rice productivity by addressing issues such as volatile prices, unfavorable market outlook, threat of pests and diseases, sustainable use of fertilizers and pesticides, and aging farmers (Bujang and Bakar 2019). In addition, the growth of the rice industry has also been affected by small-scale production, limited technological application, declining number of arable lands, scarcity of water resources, climate change, rapid urbanization, and labor shortage (Dung and Hiep 2017).

Rationale and Significance of the Study

Rice production can be improved either by increasing the area for paddy cultivation or by improving farm productivity through the efficient use of mechanization technologies. However, the former approach is hardly feasible in Malaysia due to the limited agricultural land. One of the more feasible strategies to increase farm productivity is by adopting proper machinery and farm technology (Elsoragaby et al. 2019) to reduce production costs, increase product value, and sustain the environment (Lazim et al. 2020). Using modern mechanization technologies would be more economical and efficient than using conventional technologies. However, mechanization technologies must be suitable to the climate, weather, and soil conditions of the local paddy field. Applying the appropriate technologies is crucial to ensure consistent production without jeopardizing biodiversity, environment, ecosystem, and human health (Dung and Hiep 2017).

Soil tillage and grain harvesting are the most energy-demanding and time-consuming operations in paddy cultivation. Mechanized soil tillage, which uses a pneumatic rubber-wheeled tractor, is reported to have poor tractive performance and trafficability due to its high slippage, thereby increasing operating cost, especially fuel cost. In harvesting, using a large combine harvester in a paddy field can cause soil compaction, hardpan breakage, higher operational costs, and higher grain losses. Moreover, such equipment has limited access to a small rice field and is difficult to transport from one place to another.

Recently, the revolution in mechanization technology has led to the introduction of new machinery for soil tillage and paddy harvesting. The new crawler-type tractor for soil tillage is relatively lighter and smaller than the conventional tractor, has higher tractive performance, and has lower operating cost. Meanwhile, a new medium-sized combine harvester has recently been available in the market; this machine causes minimum soil damage and is reported to have better field performance and lower operating cost than the conventional combine harvester.

The proper selection and management of machinery are important to maximize field performance and to minimize the operating costs of the machines. Thus, before these new machines can be fully adopted by the industry, their suitability and field performance should be evaluated by comparing them with those of conventional machinery.

Objectives

This paper aims to review the current mechanization status of paddy production in Malaysia. Specifically, the study assesses the challenges in deploying the existing machinery used for soil tillage and harvesting in paddy production in the country. The potential of the latest mechanization technologies to overcome the challenges is reviewed thereafter. In the conclusion section, several recommendations are provided on how to optimize the usage of appropriate mechanization technology to increase the farmers' yield and profit.

OVERVIEW OF PADDY PRODUCTION IN MALAYSIA

Paddy is the principal food source of more than half of the world's population. Globally, paddy is cultivated on approximately 153 million hectares of land, where 90 percent of the planted area is in Asia (Chauhan 2013). Among the largest paddy-producing countries in the world are China, India, Indonesia, Bangladesh, and Vietnam, with recorded productions in 2013 of 137, 106, 48 , 34, and 29 million MT, respectively (Omar, Shaharudin, and Tumin 2019). Table 1 illustrates the average of global rice production, consumption, area harvested, and yield from 2000 to 2016. Since rice is the staple food of most Asians, Asia alone consumes about 80 percent of the world rice production. In fact, Southeast Asia (SEA) has been the center of the world's rice economy (Baldwin 2012). In 2016, the region contributed around 16 million MT (39.9%) of the world's rice exports, with Thailand and Vietnam as the top exporters (Omar, Shaharudin, and Tumin 2019). In 2016, the shares of rice export of Thailand, Vietnam, and Cambodia in the world market were 24.5 percent, 12.9 percent, and 1.3 percent, respectively (Figure 1). The demand for rice is expected to increase as the world population, especially in Asia, continues to grow.

Despite the high amount of rice exported by Southeast Asian countries, not all countries in the region are rice exporters. For example, Indonesia imported 3.4 percent of the world's total rice import in 2016. Malaysia and the Philippines also imported about 2.2 percent and 1.2 percent, respectively, of the world's total rice import in the same year (Figure 1). In terms of harvested area, Indonesia has the biggest rice cultivation area among countries in SEA, which is 19.8 times larger than

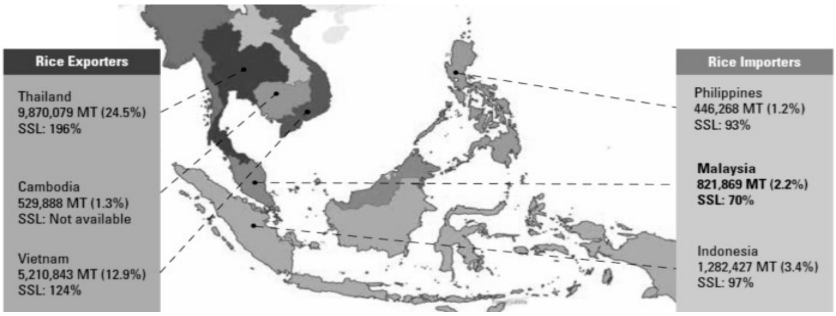
Table 1. Rice production, consumption, area harvested, and yield, Southeast Asia, 2000–16

Country	Population (in '000)	Production (in million MT)	Consumption (in million MT)	Area Harvested (in '000 ha)	Average Yield* (in MT/ha)
World	7,466,964	501.5	497.5	162,510	3.1
Asia	4,462,677	453.2	434.4	143,072	3.2
Indonesia	261,115	45.6	46.7	13,870	3.3
Malaysia	31,187	1.8	2.7	700	2.5
Philippines	103,320	12.1	13.5	4,722	2.6
Thailand	68,864	21.6	13.6	10,780	2.0
Vietnam	94,569	28.1	22.1	7,743	3.6

Source: Omar, Shaharudin, and Tumin (2019)

Note: *Average national yield for both irrigated and rainfed growing systems

Figure 1. Quantity and share of the world's rice export/import and self-sufficiency level of Southeast Asian countries, 2016



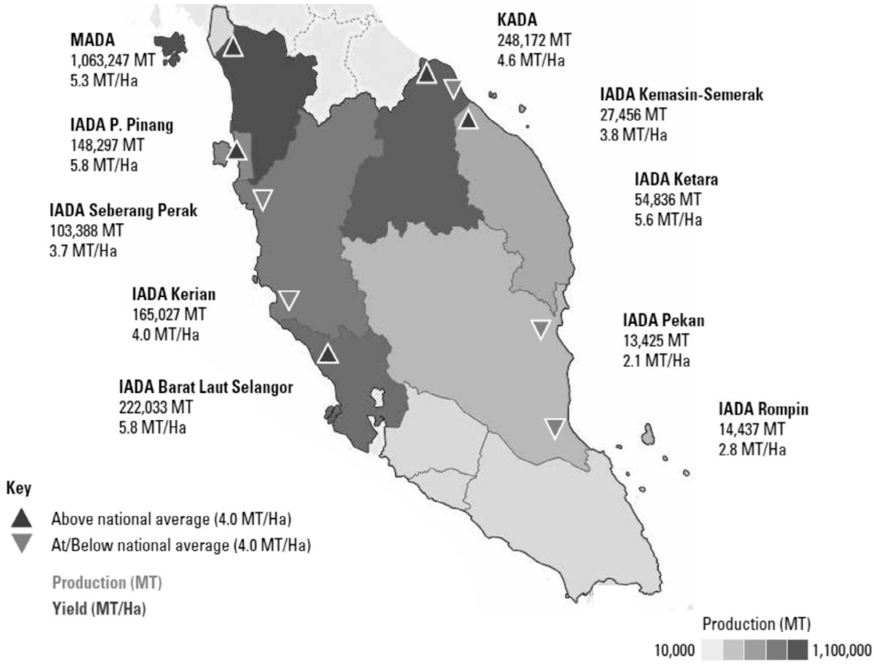
Source: Omar, Shaharudin, and Tumin (2019)

that of Malaysia. Meanwhile, Malaysia has shown an almost constant trend in rice production, harvested area, and self-sufficiency level (SSL) relative to other countries in SEA. However, it has the second highest average annual growth in rice yield at 1.6 percent after Vietnam (1.8%) from 2000 to 2016 (Omar, Shaharudin, and Tumin 2019). The average SSL of rice production in Malaysia is 70 percent (Dilipkumar et al. 2018). The Philippines, on the other hand, has shown a gradual increase in production and harvested area, with SSL hovering below 100 percent. However, Vietnam has the highest growth in rice production and SSL, with a slight increase in harvested area.

In Malaysia, paddy is the third most important crop, with the country's annual production reaching about 2.7 million MT harvested from 688,207 ha of rice granaries located throughout the country (Muazu et al. 2015). Once harvested, the paddy grains are processed into 1.8 million MT of rice to feed 31 million people. However, since the annual average domestic rice consumption is around 2.3 million MT, Malaysia still needs to import the remaining 821,869 MT of rice, primarily from Thailand, Vietnam, and India. Currently, about 194,931 farmers are involved in paddy production in Malaysia. The huge number of paddy farmers then justifies the level of attention given by the government to the well-being and socioeconomic status of Malaysian farmers (Omar, Shaharudin, and Tumin 2019).

Malaysia relies mainly on 10 key granary areas for its domestic paddy production. In 2016, the nation produced a total of 2.7 million MT of paddy. Out of this, 2 million MT or 74.1 percent of the total paddy was produced from the granary areas. The Muda Agricultural Development Authority, located in the northern peninsula of Malaysia, produced about 38.8 percent of the total national paddy production, followed by the Kemubu Agricultural Development Authority at 9.1 percent, and the Integrated Agricultural Development Area (IADA) Barat Laut Selangor at 8.1 percent (Figure 2).

Figure 2. Paddy production and yield of granary areas in Malaysia



Source: Omar, Shaharudin, and Tumin (2019)

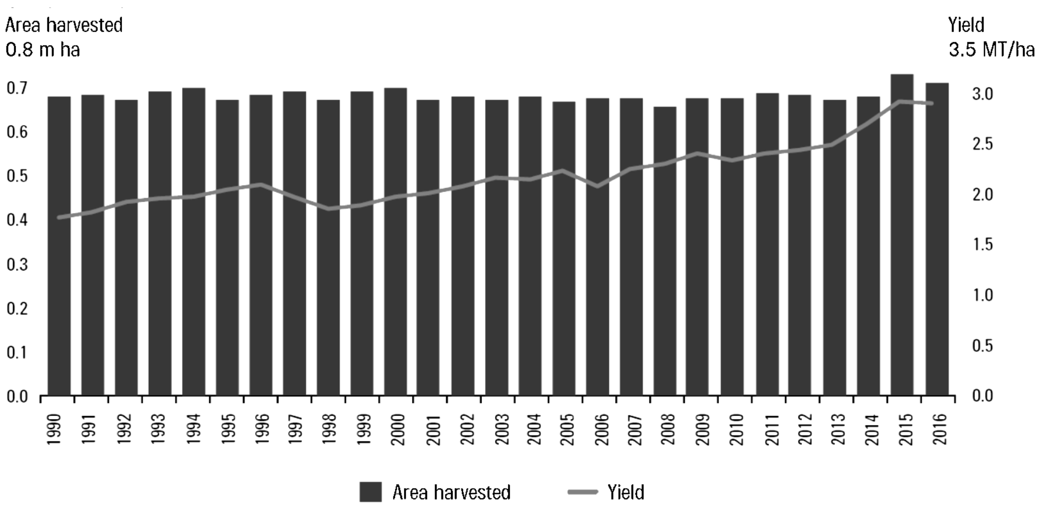
Figure 2 shows that the different granary areas in Malaysia have different yields because each area has different environmental conditions and farm practices. The average yield of paddy in the country is around 4 MT/ha, with the high-performing areas (e.g., IADA Barat Laut Selangor, IADA Pulau Pinang, IADA Ketara, and the Muda Agricultural Development Authority) having yields above 5 MT/ha. In contrast, granaries such as the IADA Pekan and IADA Rompin recorded an average yield of below 3 MT/ha.

The Malaysian government has implemented several strategies to increase paddy production from 5 MT/ha to 8 MT/ha. Increasing domestic production is vital to ensure the sufficient rice supply of the country. Accordingly, the key strategies to enhance the efficiency and productivity of paddy yield and cropping intensity in the country have been described in NAFP 2011–20. The government introduced NAFP to address three main issues, namely, ensuring food supply and safety, safeguarding competitiveness and sustainability of the industry, and increasing the income of its target groups (MOA 2016). The goal of NAFP is to strengthen the paddy industry in Malaysia through the following six strategies:

1. increase productivity and rice quality;
2. increase automation and mechanization;
3. intensify the use of rice by-products;
4. improve the management of the national rice stockpile;
5. restructure rice subsidies and incentives; and
6. strengthen institutional management of paddy and rice.

Omar, Shaharudin, and Tumin (2019) reported that NAFP has always aimed to increase paddy production to meet the national SSL targets (Figure 3). Currently, expanding the area for paddy production is almost impossible because of the limited suitable land in Malaysia and the expensive investment required for infrastructure development. However, paddy production can be increased to achieve 100 percent SSL by increasing the yield within the existing cultivation area. This strategy can be implemented by planting high-yielding varieties and by adopting good agricultural practices (GAP) in paddy cultivation. The scope of GAP covers using the correct type, amount, placement, and timing of plant inputs; using appropriate type and size of technologies; and practicing efficient farm management to increase yield while minimizing field losses (Elsoragaby et al. 2019).

Figure 3. Total harvested area and paddy yield in Malaysia, 1990–2016



Source: Omar, Shaharudin, and Tumin (2019)

CURRENT STATUS OF MECHANIZATION OF PADDY PRODUCTION IN MALAYSIA

In the last decade, on-farm mechanization of paddy cultivation in Malaysia has been well-adopted, especially in tillage and harvesting (Table 2). Based on the cultivated land area and the number of available machines, the country has enough heavy machinery to cover paddy cultivation, especially in Peninsular Malaysia. The excellent farm mechanization adoption rate can be attributed to the accommodating role of both public and private agencies and of farmers. In Malaysian paddy production, 80 percent of the field machinery is owned by private companies, while the remaining belongs to the government (Rahim 2016).

Table 2. Percentage of machinery usage according to farm activity in granary areas in Malaysia

Farm Operation	Percentage (%)
Tillage	100.0
Harvesting	100.0
Chemical application	91.0
Fertilizer application	83.0
Sowing by broadcasting	82.3
Transplanter	2.6

Source: Rahim (2016)

Muazu et al. (2014) reported that six field operations are typically involved in paddy cultivation: land preparation, seeding, fertilizing, harvesting, slashing, and chemical spraying. Tractor and combine harvester are the two primary machines used for the field operations. A tractor is used to till, slash, and level the land, whereas the combine harvester is used for grain harvesting.

In terms of land preparation, Omar, Shaharudin, and Tumin (2019) reported that about 10,000 units of tractors are being used in Malaysian paddy production; 30 percent of these equipment are four-wheel drive (4WD) tractors. However, 83 percent of the 10,000 units are owned by private service providers, while the remaining 17 percent are owned by government agencies. For example, most farmers in Sabak Bernam, Selangor state use medium-sized two-wheel drive (2WD) tractors of different makes and models, with engine power ratings ranging from 55 kW to 70 kW for tillage and slashing operations (Muazu et al. 2014). For tilling, farmers use rotary tillers with different working widths, ranging from 2.40 m to 3.18 m, attached to the tractor. Open-blade paddy straw cutters, with an average cutting width of 1.70 m, are coupled with the tractor to complete the slashing operation. Harvesting is typically done using a 7.5 MT 1545 Clayson New Holland rice combine harvester with rated engine power of 82 kW at 2,500 rpm and reel width of 4.27 m (Figure 4).

Figure 4. Typical large combine harvester used in paddy harvesting (New Holland model 1545)

Source: Wagiman et al. (2019)

Seeding, fertilizing, and spraying are done using a portable equipment that farm workers carry on their shoulders. Typically, farmers use a portable power knapsack blower, with a mass of 12 kg and engine power rating of 3.6 kW, to broadcast the pregerminated rice seeds on the puddled soil. The same blower is used to apply fertilizers, and a similar power knapsack mist blower is used to spray pesticides.

Muazu et al. (2014) characterized the machinery energy involved in paddy cultivation in Malaysia (Table 3). Harvesting consumes the highest machinery energy at 336.814 MJ/ha, which is 70.5 percent of the total machinery energy consumed in mechanized paddy cultivation. This is followed by tillage operations (first, second, and third tillage), which account for 22.8 percent or 108.730 MJ/ ha (1.454 kg/ha). Slashing expends about 24.91 MJ/ha (0.325 kg/ha) of energy, accounting for 5.2 percent of the total machinery energy consumption. Seeding requires the least energy (0.945 MJ/ha or 0.012 kg/ha), which accounts for 0.2 percent of the total machinery energy expenditure.

Overall, the total energy consumption required for producing paddy in Malaysia is 477.78 MJ/ha. In developed countries, Muazu et al. (2014) cited that rice farmers in California and Japan expend machinery energy of around 1,506.96 and 753.48 MJ/ ha, respectively, which are higher than that in Malaysia. Compared with developing countries such as the Philippines, the machinery energy consumed to produce rice is only about 173.40 MJ/ha, which is relatively lower than that in Malaysia. This trend indicates that developed countries rely heavily on machinery for the field operations in rice production. Conversely, the low machinery energy use in developing countries indicates that most field operations still rely on manual labor.

Table 3 shows that harvesting and tillage are the most energy-demanding operations. Similarly, Wagiman et al. (2020) reported these two operations as the most energy-demanding and time-consuming in paddy cultivation. Theoretically, if the energy expenditure of these two can be minimized using appropriate machines, then paddy production cost can be substantially reduced. Thus, these two field operations will be discussed in detail in the succeeding subsections.

Table 3. Distribution of machinery energy expenditure for different field operations

Field Operation	Energy Expenditure (MJ/ha)
First tillage	39.62
Second tillage	36.28
Third tillage	32.83
Seeding	0.95
Fertilizing	2.13
Spraying	3.97
Harvesting	336.81
Slashing	24.91
Total	477.78

Source: Muazu et al. (2014)

Land Preparation

Land preparation is one of the principal field operations in paddy cultivation. This operation aims to prepare a level seedbed for rice seeds, destroy existing weeds, and stimulate weed seeds to germinate in the topsoil layer. As such, the resulting weed seedlings can be eliminated through disking or harrowing before crop planting (Bhagat, Bhuiyan, and Moody 1996). In Malaysia, land preparation covers two field operations: tillage and land leveling. Elsoragaby et al. (2019) reported that land preparation typically requires three rotovations and one leveling procedure to create the necessary soil condition for rice seeds to germinate (for direct seeding method) or for rice seedlings to grow (for transplanting method).

Similarly, Mairghany et al. (2019) reported that farmers in Selangor state perform three tillage cycles every growing season. The first tillage is done to remove perennial weed species and to promote weed germination by using a tractor (59.6 kW) equipped with a rotary tiller of 2.7 m length and working depth of 15 cm. The second tillage breaks the soil and destroys the weedy rice seedlings; subsequently, the ground is leveled, and excess water is removed until the ground is properly leveled. The second tillage is usually performed after the field has undergone primary treatment to improve seedbed flatness and structure, increase soil pulverization, conserve moisture, remove weeds, and chop crop residues. The third tillage, which is also called puddling, is done to smoothen the seedbed and to level the land within the range of ± 5 cm.

Tillage operation

Tillage refers to the mechanical manipulation of the soil to develop a desirable soil structure for the seedbed and to establish a specific surface configuration for planting, irrigation, drainage, and harvesting (Osunbitan, Oyedele, and Adekalu 2005). It is performed by breaking up and pulverizing the soil to facilitate water and air movement, and thus promote plant growth.

The success or failure of paddy production largely depends on the seedbed preparation during tillage. Seedlings may fail to grow if they are planted on a hard seedbed, and thus severely affect crop productivity. Zhou et al. (2020) reported that the precise tillage of paddy fields can increase the utilization rate of manure and water and can reduce the number of weeds (Zhou et al. 2020). In addition, tillage can also improve soil bulk density, water storage capacity, and soil penetration resistance (Mairghany et al. 2019). Therefore, a thorough understanding of the effect of tillage on soil physical properties is essential for successful paddy production (Amin et al. 2014).

Meena et al. (2015) claimed that tillage is one of the important operations in paddy cultivation in the view of energy consumption, production cost, and its impacts on soil physical properties and crop yield. This is because the interaction among water, tillage, and weed management practices is complex, and this is further complicated by soil and climatic variabilities and heterogeneities (Bhagat, Bhuiyan, and Moody 1996). As such, selecting the appropriate machinery by determining the appropriate size and undercarriage system of the equipment is important to reduce the operating time and production costs of mechanized paddy cultivation, considering that the physical and mechanical soil conditions of paddy fields are unfavorable for heavy tractors (Alizadeh and Allameh 2013).

Land leveling

Land leveling is another major process in paddy cultivation. Paddy fields need to be well-leveled and filled with a uniform thin water layer of 3 cm depth. Uneven land can cause spotted flooding, which lowers the probability of seed germination in affected areas (Prakash et al. 2016). *Land leveling index* is defined as the average numerical variation (in centimeters) between the existing average level of paddy field and the intended new level (Bakar et al. 2019). Determining the land leveling index is important to ensure good agronomic, soil, and crop management practices. Accordingly, the Malaysian Agricultural Research and Development Institute published a set of guidelines that considers the trade-off between the cost of leveling and soil surface evenness (Bakar et al. 2019). The guidelines prescribe that 85 percent of the land should satisfy the leveling index 2.5 (±25 mm), or 100 percent of the land must satisfy the leveling index 5 (±50 mm) after the final land smoothing.

Figure 5. Automated land-leveling system mounted on a quad-steel-tracked tractor

Source: Bakar et al. (2019)

In Malaysia, land leveling is done using an automated land-leveling system, consisting of a controller (FmX, Trimble Inc., Sunnyvale, California, USA) and a Global Navigation Satellite System (GNSS) receiver (AgGPS 542, Trimble Inc., Sunnyvale, California USA), to acquire the required surface height data (Bakar et al. 2019). This automated land-leveling system produces an accuracy of ± 20 mm vertically and ±10 mm horizontally. The GNSS receiver is mounted on a rotary tiller while the controller is mounted on a quad-steel-tracked tractor (Figure 5).

The land leveling index is measured during the final stage of land tilling, where the GNSS receiver is mounted on the smoother flap of the rotary tiller. As the tractor moves across the field, the smoother flap follows the profile of the land. The GNSS position of the sampled data points is corrected by obtaining a correction signal from a real-time kinematic base station located at a known position. Currently, a few service providers perform this operation throughout Malaysia.

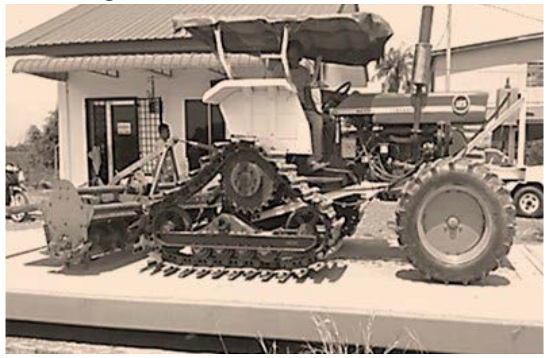
Field performance of tractors for tillage operation

Wagiman et al. (2020) conducted a study that evaluated the performance of tractors with different undercarriage systems used for tillage in paddy cultivation in Malaysia. Specifically, the authors compared the performances of rubber-wheeled tractor (RWT) and steel half-tracked tractor (HTT) in terms of their fuel consumption (FC), effective field capacity (EFC), theoretical field capacity (TFC), and field efficiency (FE). The machinery performance data were collected from three different paddy fields, namely, pida 1, pida 2, and pida 3 located in Jitra, Kedah, Malaysia. Each paddy field was divided into two equal plot sizes, namely, plots 1 and 2.

In the study, two units of 2WD tractors with 75 hp (56 kW) power size (Massey Ferguson, Model 185) were used in all tillage operations. The RWT was maintained at the original wheel setting (Figure 6), whereas the conventional wheel configuration of the HTT was replaced with a triangular steel belt system (Figure 7). Both tractors were attached with a 2.2 m rotary tiller. Table 4 presents the specification of the tractors.

Figure 6. Rubber-wheeled tractor

Figure 7. Steel half-tracked tractor



Source (both figures): Wagiman et al. (2020)

Table 4. Specification of the tractors for the tillage operation

Specification/Part	Type of Tractor			
	RWT		HTT	
	Rear	Front	Rear	Front
Brand	Massey Ferguson		Massey Ferguson	
Model	185 (2WD)		185 (2WD)	
Max engine power (hp/kW)	75 HP (55.9 kW)		75 HP (55.9 kW)	
Engine details	Four-cylinder diesel type with liquid-cooling system		Four-cylinder diesel type with liquid-cooling system	
Engine (rpm)	1701		1143	
Power take-off (rpm)	540		540	
Transmission gear system	8 forwards, 2 reverse		8 forwards, 2 reverse	
Gear selection	Low, 4		High, 1	
Implement width (m)	2.2		2.2	
Implement mass (kg)	500		500	
Tractor mass (kg)	2,010		3,630	
Total mass (kg)	2,510		4,130	
Total contact area pressure (kPa)	272		111	
Footprint area (m^2)	0.21	0.04	1.11	0.09
Weight distribution (%)	80	19	83	14
Tire/track pressure (kPa)	114	158	35	76
Tire diameter (m)	1.46	0.68	–	1.05
Track width (m)	–	–	0.69	–
Track length (m)	–	–	1.62	–

Source: Wagiman et al. (2020)

Notes: RWT = rubber-wheeled tractor; HTT = steel half-tracked tractor

The performances of HTT and RWT were tested in plot 1 and plot 2, respectively, during the first tillage (T1) and second tillage (T2). T1 was performed in a dry soil condition immediately after harvesting the previous crop to encourage good germination. T2 was performed in a wet condition to destroy the germinated weeds (Karim, Man, and Sahid 2004). The experiments for both T1 and T2 were carried out in two consecutive growing seasons within the same year (Wagiman et al. 2020).

Table 5 presents the measured tillage data collected during T1 and T2. The results showed that the area allocated to RWT (0.59 ha) was slightly bigger than that of HTT (0.55 ha). The forward speed of RWT at 4.01 km/h was 15.9 percent higher than that of HTT at 3.37 km/h. In terms of FC, RWT consumed 7.75 L of fuel, which was 30 percent higher than that of HTT at 5.96 L. The latter consumed less fuel because the track had better tractive efficiency, thus, reducing fuel consumption and soil compaction (Molari et al. 2012). In terms of effective operation time, RWT spent more time in the paddy field (0.95 hours), which was 17.3 percent longer than that by HTT (0.81 hours).

Table 5 indicates the difference in the performances of the two equipment in terms of speed, FC, and effective operation time during T1 and T2. The data showed that the forward speed of both tractors during T2 was higher than that during T1. In terms of FC, both tractors consumed more fuel during T1 than during T2. The same trend was observed in effective operation time; operation time was higher during T1 than during T2. Nawi et al. (2011) and Pebrian et al. (2013) observed similar trends.

Table 5. Measured data for the tillage operations

Parameter	HTT			RWT		
	T1	T2	Average	T1	T2	Average
Area (ha)	0.55	0.55	0.55	0.59	0.59	0.59
Speed (km/h)	3.02	3.72	3.37	3.80	4.21	4.01
Fuel consumption (L)	6.75	5.17	5.96	9.25	6.25	7.75
Effective operation time (hours)	0.90	0.72	0.81	1.03	0.86	0.95

Source: Wagiman et al. (2020)

Notes: T1 = first tillage
T2 = second tillage

T1 was done on disturbed soil under dry conditions postharvest. As such, T1 was performed at a relatively lower speed as compared with T2, which was done on wet soil. Moreover, the presence of paddy residues in the rice plot due to harvesting caused the tractors to run slower during T1. The slow operation thus required more fuel and prolonged the effective operation time to complete tillage in a given study area.

Table 6 presents the performance data of both tractors taken during T1 and T2. The results showed that the average value of TFC of HTT was 0.74 ha/h, whereas that of RWT was 0.89 ha/h. This shows that the TFC of RWT is 20 percent higher than that of HTT. Since both tractors used the same implements, the varied values of TFC were due to the different operational speeds and plot sizes of the two tractors. Meanwhile, HTT recorded an average EFC of 0.70 ha/h, which is 8.6 percent higher than that of RWT at 0.64 ha/h. In terms of FE, HTT was more efficient (94%) than RWT (72%). As regards to FC, HTT consumed more fuel at 10.89 L/ha than RWT at 13.82 L/ha. The average fuel cost of HTT and RWT were MYR 21.78/ha and MYR 27.64/ha, respectively (based on average diesel price of MYR 2.00/L in 2020). In summary, the findings show that HTT had higher FE and lower FC than RWT, which suggests that the former could be a better choice of equipment for tilling rice fields (Wagiman et al. 2020).

Table 6. Performance data for the tillage operations

Parameter	HTT			RWT		
	T1	**T2**	**Average**	**T1**	**T2**	**Average**
TFC (ha/h)	0.66	0.82	0.74	0.84	0.93	0.89
EFC (ha/h)	0.62	0.77	0.70	0.58	0.69	0.64
FE (%)	93.00	94.00	94.00	69.00	74.00	72.00
FC (L/ha)	12.25	9.53	10.89	16.66	10.97	13.82
FCt (MYR/ha)	24.50	19.06	21.78	33.32	21.94	27.64

Source: Wagiman et al. (2020)

Notes: EFC = effective field capacity
FC = fuel consumption
FCt = fuel cost
FE = field efficiency
TFC = theoretical field capacity

In terms of performance per season, the TFC, EFC, and FE of both tractors were higher in T2 than in T1 (Table 6). Regarding FC, both tractors required more fuel in T1 than in T2. HTT spent about 12.25 L/ha in T1, which is 28.5 percent more than that in T2 (9.53 L/ha). The same trend can be observed in RWT, with FC of 16.66 L/ha in T1 or 34.15 percent higher than the FC in T2. This finding is consistent with the study of Muazu et al. (2014), who reported that FC during the first tillage is more than that in the second tillage. Meanwhile, the average fuel costs of HTT and RWT were MYR 21.78/ha and MYR 27.64/ha, respectively (based on average diesel price of MYR 2.00/L in 2017) (Table 6).

Both tractors had higher FE in T2 than in T1. Although RWT used rotary tillers with the same working width of 2.4 m to carry out both T1 and T2, FE was higher by 7.3 percent in T2 than in T1. This trend is consistent with the study reported by Muazu et al. (2014), who found that a better field performance to the tune of 7.4 percent was recorded during T2 over T1.

Paddy Harvesting

Harvesting is another important operation in paddy production. Traditionally, it is regarded as labor-intensive in paddy cultivation (Bautista and Javier 2005). Accordingly, Malaysia has long been using a combine harvester to tackle its labor shortage. However, the performance of any combine harvester varies with respect to the field and machine operational conditions (Bawatharani, Dharmasena, and Bandara 2015). Thus, maintaining the effective working conditions and optimal performance of a combine harvester is important in paddy production.

Typically, most paddy harvesting contractors in the country use a large self-propelled rice combine harvester equipped with a five-meter-width cutter bar and a five-tonne-capacity grain tank. This kind of combine harvester has good effective field capacity to justify the short time slot available for crop harvesting. On most occasions, paddy harvesting must be completed as soon as possible to minimize the yield losses incurred from overripe crops due to incoming unfavorable weather condition. Recently, around 30 percent of the harvesting contractors have deployed medium-sized combine harvester as an alternative to the large combine harvester. Deploying medium-sized combine harvester is particularly useful for harvesting paddy in a small paddy field or in areas inaccessible by large combine harvesters due to soft soil condition.

Field performance of combine harvesters

Similar to the tractor performance study previously discussed in the last section, Wagiman et al. (2019) conducted a comparative study on the field performance of combine harvesters. In particular, the authors evaluated the field performances of large- and medium-sized combine harvesters under similar field conditions in Kedah, Malaysia. The study aimed to measure FE, EFC, FC, and the field machine index (FMI) of both types of combine harvesters. In the study, two models of large combine harvester (LCH) were chosen, namely: New Holland 1545 (Figure 4) and New Holland 8070 (Figure 8). The medium-sized combine harvester (MCH) was represented by Kubota DC-95M (Figure 9). Since these three are the predominant models used by contractors in this state, they were selected for the study. Table 7 details the specifications of these combine harvesters.

The results of the study showed that the EFCs of both LCH and MCH during paddy harvesting were 1.30 ha/h and 0.91 ha/h, respectively. Meanwhile, the FE of MCH was 0.78 percent higher than that of LCH. The FMI of LCH and MCH were 0.86 and 0.87, respectively. As for FC, LCH consumed 0.26 L/ha more fuel than MCH. Based on these results, the authors implied that MCH is more efficient for paddy harvesting. Moreover, MCH was more fuel efficient than LCH. The time loss of MCH to harvest paddy was less than that of LCH since the former had the highest FMI values.

Figure 8. Typical large combine harvester (New Holland model 8070)

Figure 9. Typical medium combine harvester (Kubota model DC-95M)

Source (both figures): Wagiman et al. (2019)

Elsoragaby et al. (2019) conducted a similar comparative study and evaluated the field performances of medium- and large-sized combine harvesters in Selangor, Malaysia. The authors compared the field performance of a conventional combine harvester (CCH) and the newly introduced medium-sized combine harvester (MCH) as shown in Figures 10 and 11, respectively. The comparative study was conducted during actual paddy harvesting under real field conditions. The technical specifications of both machineries are shown in Table 8.

Table 7. Specifications of the combine harvesters used for paddy harvesting

Specifications	Type of Combine Harvester		
	New Holland 1545	**New Holland 8070**	**Kubota DC-95M**
Maximum engine power (kW)	96.00	103.00	75.00
Implement width (m)	3.58	4.57	2.48
Total body weight (kg)	6,450.00	8,240.00	3,550.00
Footprint area (m^2)	1.52	1.07	1.95
Total contact pressure (kg/m^2)	4,243.42	7,700.93	1,820.51
Total contact area pressure (kPa)	41.61	75.52	17.85

Source: Wagiman et al. (2019)

Figure 10. Paddy harvesting using a typical large combine harvester

Figure 11. Typical medium combine harvester (Kubota model DC-95M)

Source (both figures): Elsoragaby et al. (2019)

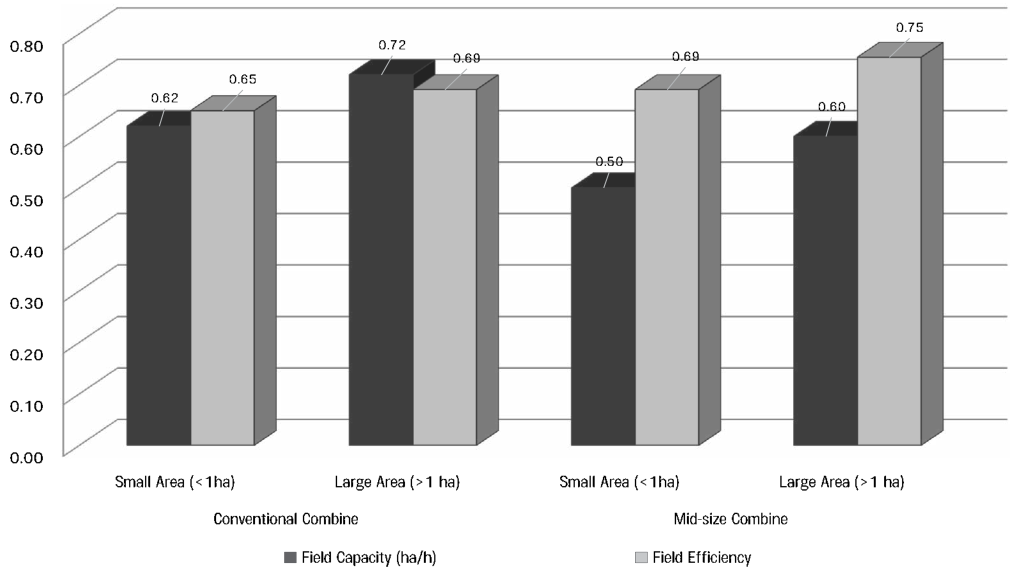
Table 8. Technical specifications of the conventional and medium-sized combine harvesters

Parameter	Conventional Combine Harvester	Medium-Sized Combine Harvester
Brand	New Holland	World Star
Model	Clayson 8080	WS7.0 Plus
Max power (kW)	82	75
Rated speed (rpm)	2,500	2,600
Total mass (MT)	10.0	3.4
Tracking tire	Half-track	Full track
Fuel type	Diesel	Diesel
Fuel tank capacity (L)	350	130
Grain tank capacity (MT)	3.5	0.8
Unloading discharge (kg/s)	8.70	1.68
Working width (m)	5.0	2.2

Source: Elsoragaby et al. (2019)

The results of Elsoragaby et al. (2019) showed that the mean EFC of CCH at 0.72 ha/h was 20 percent higher than that of MCH at 0.60 ha/h when the machine was operated in a large-sized field (>1 ha) (Figure 12). The mean FE of CCH was 69 percent, which was 8.4 percent lower than that of MCH at 75 percent. Meanwhile, the mean FC of CCH at 19.75 L/ha was 14.6 percent more than that of MCH (17.23 L/ha). When the harvesting was done in a small-sized field (<1 ha), on the other hand, CCH showed 24 percent higher mean EFC (0.62 ha/h vs 0.50 ha/h), 5.93 percent lower mean FE (65% vs 69.10%), and 3.94 percent higher mean FC (20.527 L/ha vs 19.748 L/ha) than MCH. The results reveal that MCH is more suitable to use than CCH for paddy harvesting in Malaysia.

Figure 12. Field performance (based on farm sizes) of large- and medium-sized combine harvesters



Source: Elsoragaby et al. (2019)

CHALLENGES TO THE ADOPTION OF MECHANIZATION IN PADDY PRODUCTION

One of the main challenges to the effective adoption of mechanization technology in paddy production in Malaysia is the size of the machinery. Tractors and combine harvesters are some examples of heavy and large agricultural machines typically deployed in a paddy field. These machinery, although they can increase productivity, have also been blamed for causing *soft soil condition*. Soft soil is the condition in which the soil has high compressibility and low strength, with a hardpan layer of less than 0.3 MPa at 30 cm soil depth (Rendana, Idris, and Rahman 2017). Soft soil condition is caused by the extensive use of heavy machinery that damage the soil hardpan layer (Ahmad, Khadzir, and Isa 2015). A soil hardpan layer is required in paddy fields to prevent water leakage and support the weight of machinery (Hemmat and Taki 2003).

Another common problem in a paddy field is *soil compaction*. The soil in a paddy field becomes compacted when heavy machines, such as tractors and combine harvesters, are used. When soil is compacted, its physical properties (e.g., soil structure, pore space, density, etc.) will change, which will consequently affect plant growth and development. Soil compaction is measured by the value of cone index (Kumar et al. 2012). The cone index is a measure of the resistance of the soil to penetration and is regarded as an indicator of soil strength (Mastura 2011). Kumar (2012) conducted a study on soil cone index in relation to soil texture, moisture content, and bulk density for no-tillage and conventional tillage. Accordingly, the study found that the cone index values in both no-tillage and conventional tillage decreased with the increase in clay fraction; conversely, the values increased as the sand and silt fractions of soil increased. Similarly, Mairghany et al. (2019) investigated the effects of short-term repeated passes tillage operations on bulk density, soil penetration resistance, soil porosity, and the moisture of a clay loam soil in Malaysia. The study concluded that bulk density, particle density, porosity, moisture content and soil resistance penetration were affected by repeating passing tillage. For example, bulk density of the soil was decreased after three times of tillage operations.

Using high-ground contact pressure pneumatic rubber tires on paddy fields can also damage the paddy soil (Vial, Molesworth, and Lefroy 2020); unfortunately, tractors equipped with this type of tires are commonly used for tillage in Malaysia. This type of tires, which has small contact area on the ground surface, can exert significant pressure to the soil surface, especially when these tires are installed on tractors and combine harvesters with a total mass of more than 5 MT (Taghavifar and Mardani 2013). Pneumatic-wheeled tractors are also reported to have poor tractive performance and trafficability due to their tendency for high slippage. Moreover, using machinery equipped with rubber tires on paddy fields can lead to lower field efficiency and higher operating cost.

In terms of harvesting, using CCH has been reported to cause several operational problems. For one, using the large and heavy CCH, which was originally designed for wheat, has frequently caused land compaction, road damage, higher postharvest losses, and bogging of the machine during operation, especially on soft and watery terrain (Elsoragaby et al. 2019). Moreover, the damages on the terrain surface caused by the combine movements compel farmers to rotovate and level their field plots in the following crop season. In some cases when the damage to the surface terrain and soil conditions are too severe, farmers need to perform up to five rotovations just to prepare the soil for seeding or planting (Muazu et al. 2014).

In another study, Wagiman et al. (2019) also claimed that using large and heavy combine harvesters in paddy fields may be the root cause of several problems such as soil compaction, hardpan breakage, higher operational costs, higher maintenance cost due to imported parts, and higher grain losses. Moreover, large machines are difficult to use in a small rice field and is difficult to transport from one place to another.

IMPROVING THE MECHANIZATION TECHNOLOGY FOR PADDY PRODUCTION IN MALAYSIA

To overcome the challenges attached to the use of pneumatic rubber tires, experts have recommended using tracks as an undercarriage system for farm machinery. Agricultural tracks provide better traction performance and mobility and can reduce soil compaction (Fukushima, Katagiri, and Mitsuoka 2019). Several options for agricultural track configurations are now commercially available, including full-tracks, half-tracks, and four half-tracks or quad-tracks.

Potential Improvement in the Machinery for Tillage

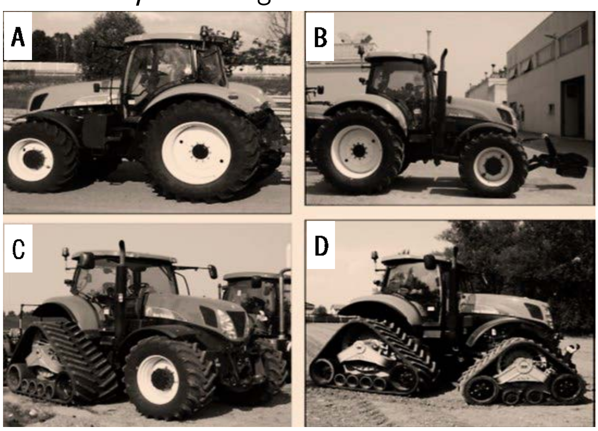
A crawler-type tractor equipped with either rubber or steel tracks have been introduced and have become popular among farmers due to its high tractive performance, efficient fuel consumption, and better trafficability (Molari et al. 2012). Tracks can increase the soil contact area, which will then reduce soil vertical pressure and increase the cohesion component in the horizontal shear force developed in traction. Tracks also reduce soil compaction, sinkage, and rolling resistance; thus, they can increase gross and net tractions as well as tractive efficiency (Keen et al. 2012). Several studies that compare the performance of tracked tractors with wheeled tractors have been conducted (Burt 1993; Bashford and Kocher 1999; Yamakawa et al. 2003). These studies have concluded that tracks perform better than tires over a wide range of soil conditions.

Several experiments have also been done to compare the performances of wheeled and tracked tractors. Accordingly, these studies have concluded that from a technical and operational point of view, wheeled tractors have an obvious advantage, albeit they have limitations in terms of mobility and tractive efficiency in the field (Burt 1993). A tractor with rubber tracks also has higher velocity during road transportation (Okello, Dwyer, and Cottrel 1994). Although tracked tractors are more technically complex and have limited maneuverability, they have advantages in terms of trafficability and tractive performance (Yamakawa, Watanabe, and Satoh 2003).

Laboratory and field analyses have shown that resorting to tracked tractors on paddy fields can reduce soil compaction and reduce the damages to the soil structure (Ansorge and Godwin 2009). However, the use of steel-tracked tractors has declined in recent years because of their mobility issue on paved roads and due to the improvements in the tire design of wheeled tractors. In fact, single-belt, high-performance rubber tracks have been recently introduced and utilized by farmers in paddy production due to their good road performance and because these produce less noise than steel tracks when moving (Bashford and Kocher 1999).

Several studies have confirmed that compared with steel tracks, rubber tracks have better tractive efficiency on the field and have lesser negative impacts on the soil (Arvisson et al. 2011). Based on these principles, rubber half-tracked solutions have been proposed for 2WD and 4WD conventional tractors. This solution has also been expanded to the axles of conventional and articulated tractors. Molari et al. (2012) evaluated the performance of tractors equipped with standard tires, water ballasted tires, half-tracks, and fully tracked (see Figure 13) in terms of their propensity to cause soil compaction and drawbar power on both asphalt and soil. Their results showed that with respect to others, the four-rubber-tracks tractor has better tractive efficiency and causes less soil compaction.

Figure 13. Different undercarriage system configurations for a tractor



Source: Molari et al. (2012)
Notes: A = 4WD, B = 4WD ballasted, C = half-tracked, D = fully tracked

Figure 14. Triangular rubber tracked tractor attached with a rotary tiller

Source: Taufik, Khusairy, and Zaman (2020)

Half-tracked and triangular rubber-tracked tractors have been recently imported into Malaysia. Correspondingly, Taufik, Khusairy, and Zaman (2020) evaluated the field performance of a tractor equipped with a triangular rubber-tracked system in terms of its machine performance, slippage, and soil-bearing capacity (Figure 14). The tractor, which was installed with oscillating crawler units, was reportedly more stable on uneven ground surface (Fukushima, Katagiri, and Mitsuoka 2019). Based on the study, the authors concluded that the tractor had excellent maneuverability, with an ability to turn 360° within a small area. In addition, the tractor produced less ground effects as it used low ground contact pressure tracks.

Meanwhile, Zhou et al. (2020) reported the latest innovation in land-leveling machinery technology and developed a new laser-controlled leveling-beating technology for paddy field preparation. The authors achieved a precise soil beating after leveling by installing the leveling device in front of the beating mechanism (Figure 15). The system was capable of leveling and beating the paddy field simultaneously using an adjustable beating depth. A field test of the leveling-beater was conducted to compare the performance under both manual and automatic control modes; the roll angles of the tractor and the leveling-beater were then measured using two attitude and heading reference systems (AHRS). The GNSS was used to measure the changes in the grade of the leveling-beater. The results of the study demonstrate that the laser-controlled leveling-beater can significantly improve the flatness of the paddy field. Contractors provide land-leveling services throughout grain granary areas in Malaysia.

Figure 15. Land leveling operation using laser-controlled leveling-beater

Source: Zhou et al. (2020)
Notes: 1 = AHRS for tractor body, 2= GNSS antenna, 3 = AHRS for leveling-beater

Potential Improvements in Harvesting Operation

Lately, the advent of MCH has piqued the interest of farmers and contractors to use the machine. As a result, around 30 percent of the rice-harvesting contractors in Malaysia have started using MCH, which is relatively smaller and lighter than the LCH. Most farmers and contractors prefer small machines due to their affordability, low running cost, and ease of handling. MCH is equipped with rubber tracks for its undercarriage system, which improves its field performance as they minimize slippage and operating cost. By using MCH, the probability of destroying the field surface decreases; it can also reduce the number of rotovations needed for a paddy field (Elsoragaby et al. 2019).

To confirm the advantages of MCH over LCH, empirical studies should be conducted to compare the field performance of these machines. The investigation should also consider different types of rice varieties at various field conditions to optimize the operational factors (Chegini 2013).

RECOMMENDATIONS

Agricultural machineries come in different sizes, types, and functions. Accordingly, the performance of such machines needs to be properly tested before they can be used in the field to ensure that their field performance and operational costs are optimal. The performance data of the different tractors and combine harvesters employed in the paddy field are essential for efficient farm machinery management.

Normally, field tests are conducted to evaluate the performance of different ranges of tractors under identical operating conditions (Muazu et al. 2014). The soil physical and dynamic properties are also measured after each operation to determine the effect of the machine on soil compaction (Ahaneku and Onwualu 2007). The proper selection of machines and implements for a particular farm situation is also crucial to minimize the energy inputs put into crop production (Al-Suhaibani 1992).

Recently, around 30 percent of paddy-harvesting contractors in Malaysia have started using MCH, which is smaller and lighter than the typical combine harvester (Wagiman et al. 2019; Elsoragaby et al. 2019). For tillage, some machinery contractors have employed half-tracked and crawler-type tractors for soil tillage during land preparation. However, the empirical studies that compare the field performance of these new types of combine harvester and tractor with that of the conventional machinery are very limited. Thus, such machines with new undercarriage systems should be evaluated before they are recommended to farmers. Without scientific data, the government will find it difficult to reform the paddy production system.

Several field performance studies have been conducted to understand the dynamic behavior of wet soil such that more efficient tillage implements and traction devices for paddy cultivation can be designed and developed (Pradhan, Ajay, and Rajesh 2016). The soft soil condition of paddy fields, combined with the machine's low trafficability, has caused agricultural equipment to sink excessively. Thus, examining the dynamic soil properties is highly important to solve traction problems in saturated paddy soils. Such traction problem has been a major constraint to the adoption of agricultural mechanization in rice-producing countries in Asia (Abubakar et al. 2009). The traction issue of agricultural machinery has been the topic of intensive research in the past and will continue to be in the future. The main problem in mechanizing paddy production is the development of a suitable traction device that can operate in saturated soils (Pradhan, Ajay, and Rajesh 2016).

Among the typical parameters to be evaluated when field testing farm machineries are travel reduction (wheel slippage), draft force, speed of operation, drawbar power, volume of soil disturbed, fuel consumption, effective field capacity, theoretical field capacity, field efficiency, and average width and depth of cut during ploughing. Thus, the machine suitability issue needs to be further investigated to ensure that farmers can rent or purchase the appropriate machines to maximize yield and minimize long-term damage to the land (Omar, Shaharudin, and Tumin 2019).

The tractive devices of agricultural tractors must have the capability to generate high tractive forces on soft soil surfaces to pull tillage implements. Accordingly, the choices for such devices have always been between pneumatic tires and tracks. Lately, the options available for the undercarriage system have expanded to 2WD, 4WD, steel track, and rubber track. Meanwhile, the development of theoretical knowledge on soil-machine interaction has enabled researchers to analyze the different locomotive aspects of tractors such that the performances of wheeled and tracked tractors can now be evaluated (Molari et al. 2012). Among the typical parameters measured during the performance evaluation of a tractor are field capacity, field efficiency, fuel consumption, machinery index, soil compaction, drawbar pull, slippage, and tractive efficiency (Molari et al. 2012; Muazu et al. 2014; Wagiman et al. 2019).

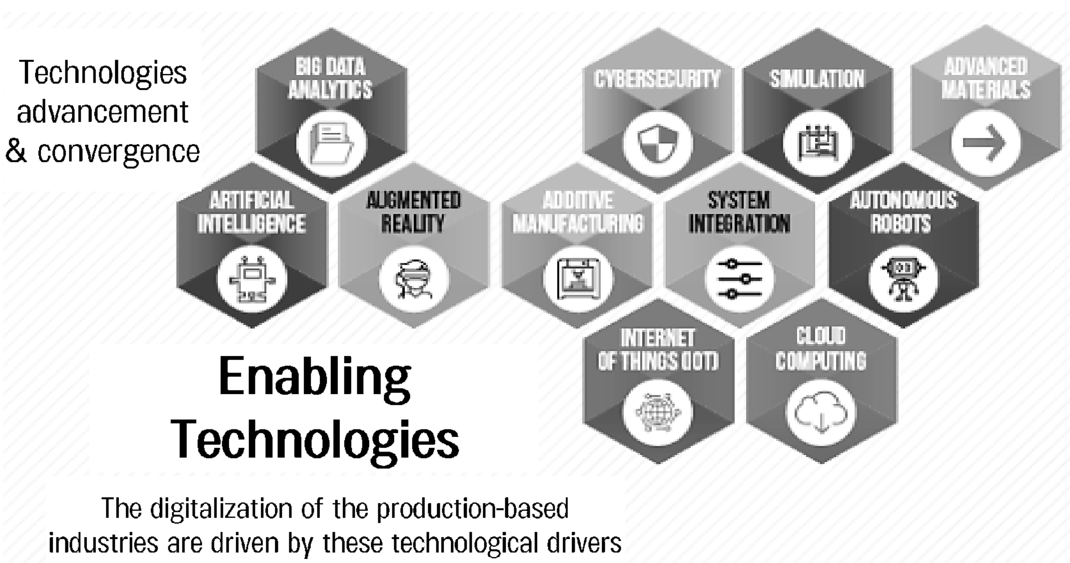
Of late, farmers have been practicing conservation agriculture (CA) as an alternative to conventional farming. CA is a planting method that practices reduced or no-till practices, retains crop residues, and applies mixed crop rotations. Adopting CA can improve soil health as the method increases soil organic carbon content; promotes aggregation; and conserves soil, water, and energy (Alam, Bell, and Biswas 2019). Soil disturbance due to tillage may decrease the topsoil organic carbon content; however, inversion tillage may bury the C-enriched soils and organic materials that can increase them in the deeper layers. In addition, CA can reduce CO_2 emissions from the soil by 4.3 MT per year, which is less than that of conventional tillage. Due to the apparent benefits of CA, it has been increasingly adopted globally and now covers about 180 million ha worldwide (Somasundaram et al. 2020). Thus, practicing CA could be promoted to paddy growers in Malaysia. However, the traditional farming mindset, socioeconomic conditions, small farmholdings, weed and residue management, and nonavailability of suitable machinery are the key constraints to the low adoption of CA among farmers, especially in South Asia (Somasundaram et al. 2020).

WAYS FORWARD
FOR MODERNIZING PADDY PRODUCTION

In addition to mechanization, automation and digitalization are also some of the important directions that need to be considered to modernize paddy production. Due to the advent of automation and digitalization technologies, farming is expected to evolve into high-technology industries, which would eventually lead to the full acceptance of the Industrial Revolution 4.0 (IR4.0). Modern agriculture would then benefit from the advent of artificial intelligence, Internet of things (IoT), robotics, and big data analytics.

The adoption of IR4.0 has been very fast due to the existing enabling technologies, such as artificial intelligence, big data analytics, augmented reality, IoT, cloud computing, autonomous robots, system integration, simulation, etc. (Figure 16). IR4.0 can facilitate the development of modern and multitasking farm machinery equipped with multiple sensors, which can carry out several farm operations and can record different field data within a single run. In addition, most of the latest machines are also attached with electronic parts, thereby allowing it to be used as a platform for implementing IR.4.0 technologies.

Figure 16. Enabling technologies for adoption of IR4.0



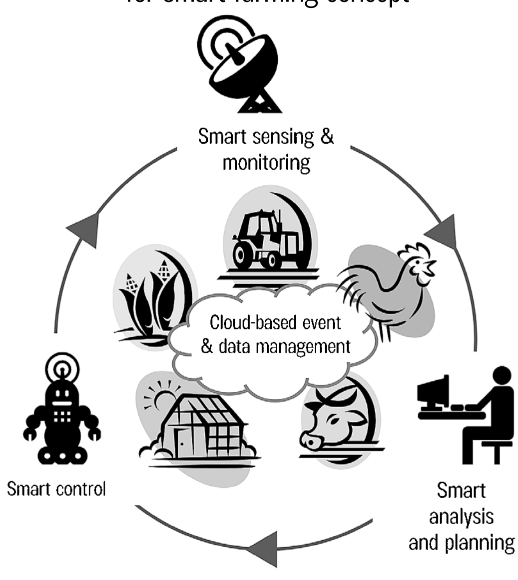
Source: MITI (2018)

IR4.0 will also promote precision agriculture (PA), which is an integrated information- and production-based farming system that can increase farm efficiency, productivity, and profitability. It can also reduce the excessive chemical application in crop production, which negatively impacts the environment and reduces profitability (Liaghat and Balasundram 2010).

Recently, technological advancements have enabled PA to be used as a tool for measuring in-field variability. While this was being promoted, the concept of smart farming was introduced to the agriculture sector. Smart farming goes beyond PA as the former bases its management tasks not only on location, but also on data enhanced by context- and situation-awareness triggered by real-time events (Wolfert, Sørensen, and Goense 2014).

Smart farming refers to the application of IoT and cloud computing technology to collect real-time data and to connect sensors with smart machines such that farm management will be data-driven and could function as a data-enabled system (Sundmaeker, Verdouw, and Wolfert 2016). Smart farming technology is important for implementing farm operations, which are always subjected to abrupt environmental change due to unfavorable weather or disease alert. To increase farm yield and efficiency, smart farming has been introduced to assist farmers in utilizing modern machinery and technologies in their farming activities.

Figure 17. The cyber-physical environment for smart farming concept



Source: Wolfert, Sørensen, and Goense (2014)

Figure 17 illustrates the concept of smart farming within the management cycle as a cyber-physical system, indicating that the smart devices connected to the Internet can control the farm system (Sung 2018). To date, due to the availability and affordability of the technologies, many studies have been published on the application of sensing and IoT technologies in support of the adoption of smart farming in paddy production (Lazim et al. 2020). Applying these technologies could allow several agricultural parameters to be monitored to improve crop yield, reduce cost, and optimize inputs such as environmental conditions, growth status, soil status irrigation, pest and fertilizers, weed management, and greenhouse gas emission (Nukala, Panduru, and Shields 2016).

Several studies have been recently published on the adoption of smart farming for the efficient management of paddy production system. Kamal and Amin (2010) developed a GIS-based user-interface technique for monitoring and scheduling daily crop water requirement for paddy. In terms of image sensing technology, Jamil and Bejo (2014) investigated the potential use of thermal imaging camera to differentiate between husk and seeds of paddy. Tripicchio, Unetti, and Giordani (2014), meanwhile, reported on the use of autonomous robot (e.g., drones) as a platform for conducting imaging sensor to get an overall survey and view of the farming area. The latest application of smart farming to paddy crop management has been developed by Athirah, Norasma, and Ismail (2020). In their study, the authors developed the mobile application Padi2U, which has multiple features in one platform. This application uses aerial images, normalized difference vegetation index, and RGB map as inputs. Accordingly, farmers can use the map to manage their paddy field in accordance with GAP.

In addition to mechanization, automation and digitalization technologies can also be used to evaluate the field performances of tractors and combine harvesters while operating in a paddy field. Field data (e.g., field capacity, field efficiency, tractive efficiency, machine index, fuel consumption, and land leveling) can be remotely measured using these technologies. A combine harvester could be installed with grain monitoring system to monitor the amount of harvested grain in a grain tank and to measure grain loss during harvest. This proposed on-line monitoring system will allow harvesting contractors to remotely monitor the performances of their machinery in the paddy field. Based on this technology, for example, a driver of a combine harvester can be immediately notified when there is a need to change any handling and setting of the machine. This approach can reduce operating costs and grain losses; hence, increase the yield of the harvested paddy. This technology is also expected to provide an optimum standard operating procedure for the machinery used in paddy production to benefit farmers, service providers, and paddy-related industries in general.

SUMMARY AND CONCLUSION

Mechanization is crucial for modernizing paddy production in Malaysia. Using the appropriate farm machinery can increase farm yield and efficiency and can also decrease production cost. However, mechanized tillage and grain harvesting have been found to be the most challenging operations in paddy production.

This paper has discussed the difficulties that farmers face in tillage and harvesting within the context of the current paddy production. In particular, soft soil and soil compaction are the two main challenges when deploying farm machinery in the paddy field. Due to soft soil condition, a typical farm machine equipped with rubber wheel experiences low tractive efficiency and high slippage. Thus, optimizing these two field operations using modern machinery equipped with suitable undercarriage systems would greatly benefit the agriculture sector.

This paper has found that the half-track tractor is more efficient and economical to use for tillage than the rubber-wheeled tractor. In terms of grain harvesting, medium-sized combine harvester offers more technical advantages compared with the typical large-sized combine harvester. However, before any new machine is introduced and promoted for use in the paddy field, its field performance should first be determined to optimize its performance and operating costs.

In addition to mechanization, the agriculture sector needs to embrace the advent of automation and digitalization technologies in farming. Adopting appropriate mechanization and automation and digitalization technologies would certainly help to improve paddy production, and thus maximize farmers' profits.

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Accelerating Transformation Through Agricultural Innovation

SEARCA has embraced the rhythms of change. Its Tenth Five-Year Plan (FYP) has directed SEARCA to move away from business-as-usual strategy as it no longer suffices in coping with the increasing complexities, uncertainties, and nonlinearities of its constantly changing environment. The "new normal" conditions in Southeast Asia compels SEARCA and all of its key partners to initiate anew a paradigm shift toward accelerating transformation through agricultural innovation in its eleventh FYP.