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Sustainable farming management: key factors and impact on paddy yields in Malaysia's granary areas

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Abstract

The paddy farmer's performance and ability to improve productivity are driven by their level of farm management practices. Knowledge on the nature and level of sustainable farm management (SFM) practiced provides opportunities for supporting the competitive advantages of paddy farmers to sustainably break away from the poverty cycle. Little attention has been given to measuring the performance and impact of SFM on the improvement of paddy farmers livelihoods in Malaysia. Without understanding SFM, it is difficult to make policies and provide targeted, impactful support to paddy farmers. This study aims to evaluate the level of Sustainable Farming Management (SFM) among paddy farmers by applying the Sustainable Farm Management Index (SFMI), in accordance with the guidelines outlined in the Rice Check (RC) by the Department of Agriculture. Additionally, it seeks to analyze the key factors and their impact on enhancing paddy yield in Malaysia's main granary areas. A set of structured questionnaire was designed to capture the eleven elements of farming practices based on the RC and was then distributed to 500 paddy farmers in Malaysia's main granary areas, namely Muda Agriculture Development Authority (MADA), Kemubu Agriculture Development Authority (KADA), and Integrated Agriculture Development Authority Barat Laut Selangor (IAD-BLS). Each practice was given a score to determine whether the guidelines were followed. The index ranges from 0 to 100, with 0 being unsustainable and 100 being highly sustainable. A multiple regression analysis was employed as well to estimate the effects of SFM adoption on farmer livelihoods. The findings show that adopting SFM has a positive and significant effect on farmers' livelihoods. The paper therefore recommends that farmers should be educated on the importance of sustainable farming practices, as this is essential for the sustainable livelihood development of the poor farmers who rely on government subsidies.

Keywords Farmer's livelihood, Granary areas, Paddy farmer, Rice Check, Sustainable farm management

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Introduction

Rice serves as the primary dietary staple for roughly half of the world's population. Its cultivation is mostly concentrated in Asia, where it constitutes approximately 90% of global rice production. In the year 2021, Southeast Asian nations contributed approximately 27% of the overall rice production in Asia [1]. Rice plays a significant role in ensuring food security, socio-cultural aspects, and strategic interventions by governments in many developing nations [2]. Paddy are predominantly grown on small-scale in most parts of the world, with the exception of Australia, the United States of America, and other South American nations. Therefore, the production of paddy serves as a means of livelihood for a significant number of small-scale farming households and landless agriculture workers throughout Asia [3].

In Malaysia, paddy contributed only RM2.4 billion (2.3%) to Gross Domestic Product (GDP) in 2020 with total production of 2,356,000 metric tons [4]. Despite the paddy and rice industry having a small contribution towards the nation's GDP, it has garnered much interest from policymakers given its complex relationship with food security, culture and socio-economic factors. Malaysian rice cultivation, which has moderate plots of less than two hectares, can thus be classified as small-scale farming [5]. A small plot of land contributes to low productivity and high production costs [6]. Due to a lack of economies of scale, paddy farmers usually trapped in poverty. Paddy farmers make up the largest portion (38.6%) of farmers in the food sub-sector [2]. In 2020, there are around 189,500 paddy farmers in Malaysia [4]. The monthly household income for paddy farmers especially in the MADA region was RM2527, which includes income from both agricultural and non-agricultural related activities [7]. This is below both the national median household income (RM5228) and mean household income (RM6958) in 2016, with paddy farmers falling within the B40 income group [2].

Besides the issue of lack of economies of scale, paddy sector also facing other issues such as high production cost, ageing farmers dominated the industry, lack of involvement youth and climate change effects. This make our country in a disadvantageous position to achieve 100% self-sufficiency level (SSL) of rice. In the NAP 2011–2020, the country aims for a 70% rice SSL. However, Malaysia's rice production was 63% self-sufficiency in 2019, falling short of the target. From 2010 to 2020, local rice consumption increased from 2690 thousand metric tonnes to 2800 thousand metric tonnes [8], with per-capita consumption of 75.6 kg/year in year 2020 [9]. This demonstrates that Malaysian rice production is still insufficient and requiring imports. Climate change is the most recent threat beyond human control affecting agricultural production, particularly rice production. Drought incidents in 1978, 1982, 1983, 1987, 1991, 1996, 2015, and 2016 impacted the production of rice due to a lack of water in the first crop season [10].

To foster the development of the paddy sector, which is crucial for both national food security and the livelihoods of farmers, the government has established eight granary areas across the country since 2007. These areas include MADA, KADA, IADA Kerian, IADA Barat Laut Selangor, IADA Pulau Pinang, IADA Seberang Perak, IADA KETARA, and IADA Kemasin Semerak. Granary area refers to massive irrigation schemes (areas greater than 4000 hectares) identified by the government in the National Agricultural Policy as the main producing areas [9]. The 3 granaries, IADA, KADA and MADA, act as bodies assigned by the Ministry of Agriculture & Agro-Based Industry Malaysia (MOA) as an assistantship to the paddy farmers [11]. They are responsible for managing agricultural infrastructure, strengthening support services and farm management, providing consultation through program, and reinforcing service agencies. Besides enhancing irrigation system through the establishment of granary area, government also provide various incentives and subsidies to encourage farmers to increase their yield. As a result, about 30–50% of the national budget allocated for the Ministry of Agriculture (MOA) goes directly to paddy and rice-related incentives and subsidies. In 2016, the government spent RM1.4 billion on price, fertilizer, yield, and seed subsidies [2].

Despite numerous programs and incentives granted to the rice sector, statistics reveal that rice production and productivity are continuously declining. Table 1 depicts rice data in Malaysia from 2015 to 2020. Malaysia's paddy planted area and number of paddy farmers have both shrunk. This was followed by a reduction in output and productivity. Rice production in 2020 was 2356 metric tonnes, compared to 2741 metric tonnes in 2015, while productivity fell from 4022 kg per hectare in 2015 to 3654 kg per hectare in 2020. Because of this issue, the government spends a significant amount of money every year on rice imports, as indicated in Table 1.

Table 1 Malaysia paddy information 2015–2020. Source: [41]

Year	2015	2016	2017	2018	2019	2020
Paddy planted area	681 559	688 770	685 548	699 980	672 084	644 908
Paddy production ('000 metric tons)	2741	2740	2571	2639	2353	2356
Average yield (kg/Ha)	4022	3978	3750	3770	3501	3654
No. of farmers	197,189	194,931	193,679	193,378	192,663	189,500
Total imports of rice ('000 metric tons)	961	748	726	776	890	1110

To ensure food security and improve paddy farmers' livelihoods, addressing major challenges and implementing sustainable agriculture practices is crucial for maintaining environmental and ecosystem balance. The Rice Check system, introduced in Australia in the 1980s, serves this purpose by enhancing yields and production quality while providing recommendations and learning tools to rice growers [12]. Through better management, farmers can precisely determine the timing and quantity of fertilizers, pesticides, and other inputs, thereby reducing pollutants in the air, soil, and water. This integrated crop management package has increased rice yields from 6 tons per hectare to 8 tons per hectare [13]. Thailand, a leading rice producer, has established several standards for rice production, including Good Agricultural Practices for Thai Hom Mali Rice (2009), Good Agricultural Practices for Rice (2008), Good Manufacturing Practices for Rice Mill and Rice Processing Plant (2021), and the Sustainable Rice Cultivation Standard (2020) [14]. These standards aim to boost crop productivity, promote sustainable cultivation, and enhance global market opportunities for Thai rice, focusing on quality, food safety, the economy, society, and the environment [14]. In Malaysia, the Rice Check system was established in 2002 under the Department of Agriculture, with the latest revision released in 2022. It includes guidelines for rice cultivation covering soil preparation, planting, fertilizer and water management, integrated pest management, harvest and post-harvest management, and environmental management [15]. Each practice requires farmers to closely monitor their fields to ensure optimal outcomes.

Clearly, sustainable agriculture guidelines in paddy production have been implemented in most paddy-producing countries, and numerous empirical studies have been conducted to assess the level of adoption and effectiveness for farmers. Rika et al. [5] estimated the Paddy Farmer Sustainability Index (PFSI) to examine the degree of sustainability at the field level under current paddy farming systems, based on 30 current practices, involving 61 paddy farmers in the Farmer Organization Association (PPK) regions of KADA, Kelantan. The PFSI was measured on a scale of 0 to 100. The results indicated that the average sustainability level in paddy farming is relatively unsustainable, and Chi-square analysis shows that the level of farmers' awareness towards sustainable agriculture and their positive attitudes significantly differ from the level of PFSI. In India, Bonny and Vijayaragavan [16] developed the Farmer Sustainability Index with 40 items, covering insect control, disease control, weed control, soil fertility management, soil erosion control, and other related practices relevant to the local conditions of farmers. This index was created to measure the adoption of sustainable practices by traditional Indian paddy farmers. The results illustrated a wide range in the mean Farmer Sustainability Index scores between two groups of paddy farmers: conventional farmers and more sustainable farmers. The former type of farmer had an index score of 23.95, while the latter had a score of 70.06, indicating that those practicing sustainable farming systems were more sustainable than conventional farmers.

Regarding the determinants of sustainable agriculture practices, particularly in paddy cultivation, Mohamed et al. [17] identified two significant factors contributing to the unsustainability of paddy farming in the KADA region, Malaysia: awareness of the existence of Rice Check and knowledge about sustainable practices. Ahmadpour [18] found that the application of sustainable agricultural practices was generally good among paddy farmers in Sari County, Iran, highlighting farm size, economic facilities, participation in extension training courses, and age as significant factors in adopting sustainable practices by farmers in rural production cooperatives. Additionally, Donkoh and Awuni [19] demonstrated that extension visits and farmers' experience positively influenced the adoption of sustainable farm practices, while farm size, landownership, and input distance had negative effects. They emphasized the need to improve farmers' field schools and extension delivery systems, ensuring timely support to maximize impact. Furthermore, Sukayat et al. [20] pointed out that a farmer's education level and active participation in farmers' groups are also important in achieving sustainable farming.

In particular, weed and pest control are critical focus areas for crops like rice, which require substantial amounts of fertilizers, herbicides, and pesticides to remain healthy and productive. Due to concerns about the negative effects of pesticide use in paddy cultivation, Hairuddin et al. [21] specifically studied the effectiveness of the integrated pest management (IPM) program, a key component of the Malaysia Rice Check program. The IPM practices in paddy production initiatives include research on the optimal use of pesticides, complementary weed control strategies, and alternative cultural and biological controls. The study's results demonstrated that the IPM program generates economic benefits, including improvements in water quality, food safety, pesticide application safety, and the long-term sustainability of pest management systems. Additionally, the savings in environmental costs and the reduction in pesticide use also lowered operating expenses. The calculated economic benefits, in terms of aggregate cost savings per season for 454 farmers, were MYR 756,393 for insecticides, MYR 40,537 for herbicides, and MYR 94,753 for fungicides.

Previous studies have primarily focused on the level of sustainable agriculture practice and its determinants.

However, it is crucial to identify the factors influencing farmers to adopt established standards and whether these practices increase paddy yield. A key strategy to improve farm management practices towards sustainable agriculture development, especially in paddy production, is to demonstrate its significant impact on enhancing paddy farmers' livelihoods. Once this impact is empirically proven, it will motivate farmers to fully adopt these practices. Furthermore, no empirical study has yet highlighted the importance of farm management in boosting the income and livelihoods of rice farmers, particularly in Malaysia. Hence, the objective of this study is to assess the degree of sustainable farming practices based on Rice Check technology, identify its determinants, and evaluate how these practices contribute to the livelihoods of paddy farmers in Malaysia's main granary areas by improving their paddy yield.

Methodology

Results from this research are based on a primary data collected through a face-to-face interview with paddy farmers that was conducted from March to August 2021. A set of structured questionnaires was developed in accordance with the Rice Check guideline that has been stipulated by the Department of Agriculture, Malaysia to indicate Sustainable Farm Management (SFM). We also ask for the respondents' socio-demographics details and institutional information to be subsequently used to explain the factors influence the livelihood of paddy farming in conjunction with SFM.

In this study, the samples were drawn through application of stratified random sampling strategy. The unit analysis for this study was the paddy farmers in main granary areas of Malaysia namely Muda Agricultural Development Authority (MADA), Kemubu Agricultural Development Authority (KADA) and Integrated Agricultural Development Authority, Barat Laut Selangor (IADA-BLS) areas. Paddy farmers in this study referred to those who were engaged in paddy production activity either on full- or part-time basis and who had registered with the MADA, KADA and IADA-BLS. According to the paddy farmer lists provided by each organization, MADA has 57,635 farmers, KADA has 36,582 farmers, and IADA-BLS has 9754 farmers. The sample was then stratified by granary area. Finally, an equal ratio of farmers was selected at random to yield a predetermined total sample size of 500 (275 MADA farmers, 176 KADA farmers, and 47 IADA-BLS farmers) for investigation. If the population is larger than 210, the minimum sample size, according to Krejcie and Morgan [22], is 384. Thus, the predetermined sample size of 500 in this research passes the statistical requirement.

Table 2 presents the socio-demographic characteristics of rice farmers in the MADA, KADA, and IADA-BLS regions. The majority (93.1%) of farmers are men, with 6.9% being women. Farmers aged 60 and above make up 34.2% of all rice farmers, followed by those aged 50 to 59 at 27.5%. The age distribution is similar across the three regions, with farmers aged 50 and above constituting over half of the population, indicating that rice production in Malaysia is dominated by the elderly. However, the involvement of youth aged 20 to 29 is promising, accounting for 7.4% of all paddy farmers, with regional participation at 7.3% in MADA, 9.5% in KADA, and 3.9% in IADA-BLS. Educational attainment varies by region. In MADA and IADA-BLS, 50.2% and 40.4% of farmers, respectively, have completed the high school-level SPM/MCE/SPVM examination. In contrast, educational attainment in KADA is lower, with 33.6% having completed the lower secondary school-level PMR, SRP, or LCE exams.

Most rice farmers (62.7%) have over a decade of experience, indicating a high level of expertise in paddy cultivation. In terms of production scale, a significant proportion of farmers engage in small-scale production with less than 2 hectares of land, particularly in MADA (67.3%) and IADA-BLS (45.5%). In contrast, in KADA, 50.5% of farmers engage in medium-scale cultivation, while 31.5% are involved in large-scale production. The disparity in land rental values, with KADA at RM500/hectare and MADA at RM1500/hectare, allows KADA farmers to access more land.

Rice farmers' total income is influenced by factors such as age, education level, experience, and field size. Many farmers' earnings fall within the B1 income category (RM2500 and lower), with the highest proportion in IADA-BLS (86.0%), surpassing those in MADA and KADA. This suggests that while farming techniques in IADA-BLS are more advanced than in MADA and KADA, they do not significantly impact farmers' income. Contributing factors to the low income in IADA-BLS include higher rice cutting rates at factories (26–30% compared to 18–20% in MADA and KADA) and higher land rental costs (RM3000–3500/hectare compared to RM500–1500/hectare in MADA and KADA).

The Sustainable Farm Management Index (SFMI) was employed to assess the degree of farm management for individual farmers, based on the approach established by [5, 23]. There are 10 components in Rice Check, which are further divided into 68 production practices. These practices encompass various stages of rice production, starting from the assessment of land suitability and preparation of paddy fields to tillage, planting, fertilization management, water management, integrated pest management, harvest management,

Table 2 Socio-demographic characteristics of paddy farmers

Demographic variables	MADA	KADA	IADA-BLS	Overall
Gender				
Female	11.4	2.7	5.6	6.9
Male	88.6	97.3	94.4	93.1
Age				
20–29	7.3	9.5	3.9	7.4
30–39	16.5	14.2	14.6	15.2
40–49	14.9	16.9	14.6	15.6
50–59 n	28.6	24.1	31.5	27.5
60 and above	32.7	33.7	35.4	34.2
Education level				
No education	1.3	5.4	2.8	3.2
Religious school	0.3	1.0	1.1	0.8
Primary school	12.4	20	20.7	17.1
Lower secondary school (PMR/SRP/LCE)	25.4	33.6	23.0	27.9
Higher secondary school (SPM/MCE/SPVM)	50.2	28.1	40.4	39.7
STPM/DIPLOMA/SIJIL	9.5	8.5	10.1	9.3
Bachelor and above	1.0	3.4	1.6	2.0
The area of cultivated rice fields				
Small scale	67.3	18.0	45.5	43.9
Medium scale	26.0	50.5	37.1	37.7
Large scale	6.7	31.5	17.4	18.4
Household income				
B1	79.0	63.7	86.0	74.9
B2	6.3	9.2	2.2	6.5
B3	4.8	6.8	2.8	5.1
B4	1.9	7.8	2.8	4.3
M1	3.5	3.1	2.2	3.0
M2	1.0	3.7	0.6	1.9
M3	1.0	2.0	1.1	1.4
M4	1.6	1.7	0.0	1.3
T1	0.6	0.7	0.6	0.6
T2	0.3	1.4	1.7	1.0
Involvement in paddy production				
Fulltime	76.8	97.6	94.4	88.6
Part time	23.2	2.4	5.6	11.4
Experience in paddy cultivation				
Less than 10 years	40.6	42.0	23.6	37.3
11–20 years	23.2	29.5	26.4	26.3
21–30 years	22.9	15.6	19.7	19.4
More than 30 years	13.3	12.9	30.0	17.0

post-harvest handling, and environmental management (Table 3). These practices serve as indicators for measuring the SFMI. Each practice is assigned a score of 1 if performed and 0 if not. The total score is then calculated and converted into a percentage. For example, if a farmer practices 50 out of 68 components, the total score will be 73.5% [$(50/68) \times 100$]. To enhance the interpretability of the SFMI, the indices (ranging from 0 to 100) are recalibrated to a quotient scale and categorized into four distinct sustainability groups: severely unsustainable (0 to 25.0), unsustainable (25.1 to 50.0), moderately sustainable (50.1 to 75.0), and sustainable (above 75.0). The categorized SFMI scores were used to analyze the adoption level of sustainable

Table 3 Components of Rice Check in Malaysian rice production

No.	Rice Check components	
F1	*Check 1: determination of soil suitability*	
1	Engage extension officers to assess soil acidity within the optimal pH range of 5.5–6.0	
2	Are you aware of the acidity levels in the rice paddy soil?	
3	Execute liming procedures prior to planting	
F2	*Check 2: paddy field condition*	
4	Each paddy field equipped with an inlet and outlet water channel	
5	Each paddy field equipped with water control structure	
6	The width of the paddy field is 30–45 cm with a height of 15–20 cm	
7	The farm road is strong and non-leaking to control water in rice paddies and reduce rodent breeding grounds	
8	The farm road cleared of weeds to prevent the host to pests	
9	Irrigation systems, water drainage, and water control structures well functioning	
10	The width of the farm road at least 4.5 m	
F3	*Check 3: soil preparation*	
11	Controlled burning of hay	
12	Utilization of straw compost to enhance soil fertility	
13	Clearing the paddy field of straw, stumps, weeds, sweet potato, and wind rice prior to plowing	
14	Monitor of all tractor operations to ensure meticulous execution of land preparation activities	
F3i	*Soil preparation activity: plowing*	
15	Soil plowing conducted 30 days before planting (dry conditions)	
16	Plowing performed 7–10 days before planting (dry or wet conditions)	
17	Plowing carried out 1–2 days before planting (wet conditions)	
F4	*Check 4: cultivation*	
18	Use valid rice seeds certified by the Department of Agriculture	
19	Selecting rice varieties based on the suitability of the paddy field	
20	Employing the direct sow method for planting	
21	Soaking seeds for 24 h after cleaning	
22	Administering seed treatment for disease-prone rice varieties	
23	Fermenting soaked seeds for 24–48 h in a covered area	
24	Ensuring leveling and saturation of rice paddy soil with water prior to sowing	
25	Sowing seeds using a sprayer	
F5	*Check 5: fertilization management*	
26	First stage fertilization	Compound fertilizer
		Triple super phosphate (additional fertilizer)
		Muriate of potash (additional fertilizer)
27	Second stage fertilization	Urea
28	Third stage fertilization	Compound fertilizer
		Compound fertilizer (additional)
		Urea 46%
29	Fourth stage fertilization	Compound fertilizer (additional)
F6	*Check 6: water management*	
30	Water added to rice fields according to the irrigation schedule issued by the relevant agency	
31	Presence of a water lane to expedite irrigation and drainage	
32	Gradual increase in water depth in the paddy field	
33	Soil left saturated after 7 days of sowing	
34	Water depth maintained at 5–7 cm after 7–10 days of sowing	
35	Water depth maintained at 5–7 cm after 15–40 days of sowing	
36	Water depth maintained at 5–10 cm after 40–90 days of sowing	
37	Water released 10–14 days before harvest	
F7	*Check 7: integrated pest management*	
38	Spray herbicide before the first plowing	
39	Spray pre-germination herbicide after sowing the seeds	
40	Conduct herbicide spraying according to the schedule based on the Clearfield Production System Guide	
41	Spray herbicide before the reproductive stage	

Table 3 (continued)

No.	Rice Check components
42	Manually remove weeds (weeding process) at the pollination stage
43	Perform pest control following the integrated pest management (IPM) method
44	Spray insecticides before 40 Days Past Sowing (DPS)
F8	*Check 8: harvest management*
45	Dry paddy fields 10–14 days before harvest
46	Harvest rice when 85–90% of the grains on the stalk are yellow
47	Harvest in a dry and dew-free environment between 11 am and 6 pm
48	Clean the harvester to ensure it is free of wind rice, weeds, and snails before use
49	Monitor the operation of the harvester to prevent yield loss and ensure rice quality
50	Adjust the boom on the rake, cutter, and fan for efficient operation
51	Cut the rice plant at 1/3 of the height from the tip
52	Align the harvest width to ¾ of the cutting table width
53	Operate the gate at medium speed
54	Use a mini harvester for soft ground areas
F9	*Check 9: post-harvest management*
55	Covering the truck with canvas for protection
56	Ensuring the floor and walls are leak-proof to prevent yield loss
57	Transporting harvested rice to the drying complex within 24 h
58	Farmers are present during the rice grading process
F10	*Check 10: environmental management*
59	Use pesticides recommended and registered with the Pesticides Board only
60	Read and adhere to all information on the pesticide label before use
61	Repeat weed control if necessary
66	Use pesticides with different modes of action
67	Do not drain water from the paddy fields after pesticide spraying
68	Clean and puncture pesticide containers before sending them to the disposal center

farming practices among paddy farmers using descriptive analysis.

Then, ordinary least squares (OLS) multiple regression analysis was conducted to determine the factors influencing sustainable farm management (SFM) by regressing it against various socio-demographic variables, including age, experience, occupation, and farm size. Additionally, the analysis examined the influence of institutional factors, such as perceptions regarding the role of relevant institutions and the percentage of subsidized fertilizer usage, as well as technology readiness and off-farm activities, on household income. For this analysis, we used the SFMI in percentage form instead of the categorized SFMI.

The regression model used can be specified as follows:

$$\text{SFMI} = a + bi\,Zi + \cdots + bj\,Zj + u,$$

where SFMI is the percentage index representing the degree of sustainable farm management, $Z1$ is the granary area of KADA (if KADA = 1, others = 0), Z2 = granary area of BLS (if BLS = 1, others = 0), $Z3$ is the age of the farmers in years, $Z4$ is the number of years of experience that farmers have in paddy farming, $Z5$ is the dummy variable indicating the main occupation of the respondent as a paddy farmer, where 1 indicates a full-time farmer and 0 indicates a part-time farmer, $Z6$ is the technology readiness index, measured in percentage, $Z7$ is the percentage of off-farm income, $Z8$ is the perceived behavioral towards the impact of climate change on paddy production measured on a Likert scale, $Z9$ is the perceived behavioral towards the role of institution measured in Likert scale, $Z10$ is the machinery ownership, $Z11$ is the cumulative area of paddy fields that have been cultivated, measured in hectares.

Subsequently, a second-order regression analysis was conducted to examine the degree to which the individual variables of Sustainable Farming Management (SFM) influence the yield of rice. The regression model's specifications are outlined as follows:

$$Y = a + bi\,Xi + \cdots + bj\,Xj + v,$$

where Y is the yield of paddy production in Malaysian Ringgit (RM) per season, $X1$ is the determination of soil suitability, $X2$ is the rice field design management, $X3$ is the plowing preparation, $X4$ is the seeding management, $X5$ is the fertilizer management, $X6$ is the water management, $X7$ is the integrated pest management, $X8$ is the harvesting management, $X9$ is the post-harvest management, $X10$ is the environmental management, $X11$ is the transplanter usage.

Results and discussion

Adoption level of sustainable farming practices among paddy farmers

The Sustainable Farm Management Index (SFMI) is used to classify the level of sustainability into four distinct categories: severely unsustainable, unsustainable, moderately sustainable, and sustainable, as established by [5]. Referring to Fig. 1, it can be observed that more than half of rice farmers in the KADA and IADA-BLS regions have attained a sustainable management level.

Specifically, 59.7% of rice farmers in the KADA region and 76.4% of rice farmers in the IADA-BLS region have successfully achieved a SFMI of 75% or above. In contrast to the MADA region, the study's analysis revealed that a mere 41.6% of rice farmers managed to attain a level of sustainable management. However, there are no farmers obtained SFMI less than 25% which is in severely unsustainable category. This observation indicates that the degree of farm management in the MADA region is comparatively lower as compared to the KADA and IADA BLS regions, despite the fact that these regions have seen extensive development and received significant governmental focus.

Figure 2 shows the percentage of rice farmers who managed to achieve SFMI above 75%, which is categorized as a level of sustainable farm management, and is arranged according to the details component of the Rice Check. Findings show that there is no component that has been successfully practiced by rice farmers in all three granary areas. However, more than 80% of rice farmers are successfully practicing sustainable farm management for the components of seed management, water management, and environmental management. In terms of seed management, the study revealed that a significant proportion of rice farmers in MADA (92.7%) and KADA (94.6%) were able to sustainably practice seed management procedures. Farmers use a variety of rice that is both permissible and well-suited for the specific soil composition while also adopting seed treatment practices in which the rice seeds undergo an initial soaking and fermentation process ranging from 24 to 48 h, as recommended by Rice Check guidelines. In addition, prior to the beginning of the seed sowing procedure, it is essential to ensure that the paddy field is properly leveled and adequately saturated with water. However, different findings were observed for seed management at IADA-BLS. Most rice farmers do not employ the direct sowing method for seed management but instead employ transplanters, which involve transplanting seedlings using machinery rather than spraying machines. As a result, they do not follow the same procedure as described above because rice growers purchase seedlings from vendors.

For the water management component, it was discovered that rice farmers in the study regions had attained a level of sustainable water management in which about 80% of rice farmers were shown to comply with the irrigation schedule recommended by the Rice Check manual and the oversight agency. Furthermore, the condition of water channels to speed up irrigation and drainage is good, and the period for entering and exiting water is followed according to Rice Check requirements. In terms of environmental management, practically all rice farmers achieved a level of sustainable environmental management, with more than 88% of rice farmers in all regions achieving SFMIs of more than 75%. However, it was found that several components, such as the level of fertilizer management, harvest management, and post-harvest management, are at a critical level, where less than 50% of farmers practice sustainable farm management.

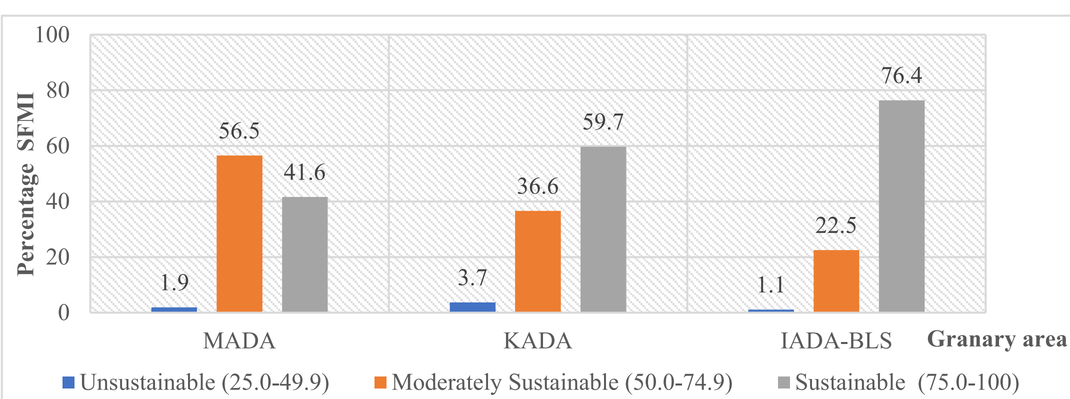

Fig. 1 Level of farm management by granary area

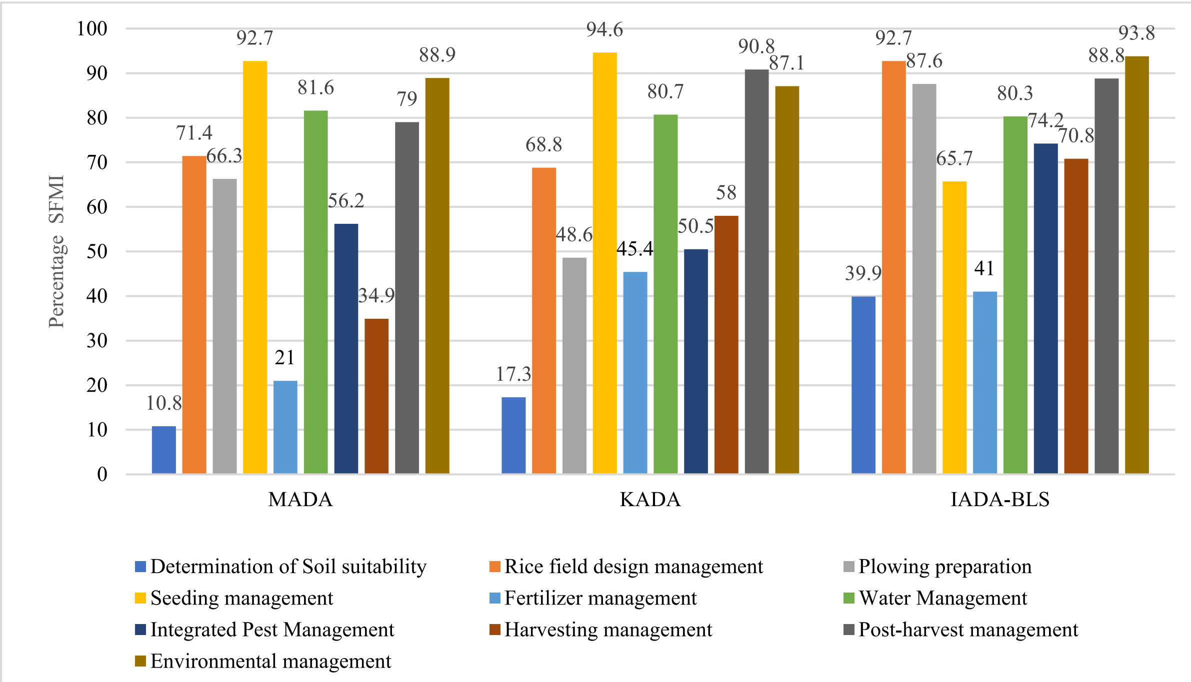

Fig. 2 Percentage of paddy farmer that achieve a Sustainable Farm Management Index (SFMI) score of 75% and above

For example, only 21% of paddy farmers in MADA, 45.4% of paddy farmers in KADA, and 41% of paddy farmers in IADA-BLS managed to practice a level of sustainable fertilizer management. While for post-harvest management, only 29.2% of rice farmers in MADA reached the level of sustainable farm management.

The results further indicate that the degree of soil management among rice farmers is rather deficient, with just 58.1% of rice farmers in MADA and 51.5% of rice farmers in KADA reaching a level of sustainable management. This situation implies that rice farmers in MADA and KADA lack knowledge regarding the acidity levels of their cultivated rice fields, neglect the liming procedure, fail to assess the present condition of the rice fields, and inadequately prepare the fields by plowing prior to sowing. According to the study conducted by [24], the adoption of soil management practices and the enhancement of soil nutrient content are crucial factors for obtaining optimal yields. Efficient deployment of nutrient management can be achieved through the subsequent process of fertilizer management, facilitated by a comprehensive understanding of soil fertility. This procedure has the potential to facilitate the production of high-quality output and maximize production.

Furthermore, it is important to note that the adoption of sustainable fertilization management practices among rice farmers is significantly lacking. Specifically, only 21% of rice farmers in MADA, 45.4% of rice farmers in KADA, and 41% of rice farmers in IADA-BLS have attained the ideal level of sustainable fertilization management. The MADA area exhibits a significant concern in terms of fertilization management, as a significant percentage of rice farmers, approximately 79%, do not adhere to the recommended fertilization procedures specified by Rice Check. This non-compliance primarily manifests in inadequate adherence to the recommended frequency of fertilization and inappropriate application of fertilizers that correspond with the level of plant growth. Azman et al. [25] posits that the application of fertilizer at an inappropriate time might hinder its absorption by the plant. The timing of fertilization is dependent upon both the maturity period of a certain plant variety and the particular stage of its growth. According to [26], the ideal time for the application of fertilizer is during the growth stage indicated by the appearance of three leaves. This stage signifies the level of active reproduction, stalk development, and stalk germination.

In the context of integrated pest management, it was observed that a substantial percentage of rice farmers in the MADA area (37.1%) and the KADA area (41.7%) exhibited inadequate adherence to weed management practices. Specifically, these farmers failed to appropriately execute herbicides in tandem with the growth stage of the weeds, omitted to adhere to the stipulated spray schedule outlined in the Clearfield Production System Manual, and did not engage in manual weed control processes. The direct sowing approach necessitates the separation of germinated and non-germinating seeds during the pollination stage. The process of pollination plays a crucial role in promoting optimal plant growth and protecting against potential insect infestations. In the IADA-BLS region, it has been observed that paddy farmers do not have any difficulties in managing weeds. Specifically, a significant majority of 85.4% of rice farmers have adopted sustainable weed management practices and adhered to the recommended management procedures. Nevertheless, rice farmers in the IADA-BLS region encounter the challenge of pest management, with around 26.4% of them failing to adhere to the integrated pest management (IPM) approach and the recommended timing for pesticide application on plants.

Moreover, the issue of harvesting management poses a significant concern in rice production within the research regions. Specifically, 60.6% of rice farmers in MADA, 39.3% of rice farmers in KADA, and 31.3% of rice farmers in IADA BLS have been seen to neglect proper harvesting procedures. The harvesting process is of utmost importance in guaranteeing the preservation and prevention of spoilage or loss of the food. Rice farmers exhibit a lack of diligence in ensuring the requisite drying period for rice fields, which should ideally span between 10 and 14 days prior to the commencement of harvesting. In addition, it is observed that rice farmers refrain from harvesting rice crops until approximately 85 to 90% of the seeds within the rice stalk exhibit a yellow coloration. The inspection of the harvester is also deemed unsatisfactory prior to the commencement of the harvesting procedure.

This issue arises due to the prevalent practice among rice farmers of using the services of other parties for the rental or hiring of harvesters. According to [27], the primary factor contributing to paddy loss during the harvesting process is attributed to the design of the harvester, the handling techniques employed, and the inappropriate timing of harvesting, which is not in accordance with the plant's growth stage. Typically, a properly maintained and precisely calibrated harvester has the capacity to mitigate the proportion of post-harvest losses. The mean percentage of post-harvest losses is 28.5%, particularly occurring throughout the stages of harvesting, transportation, drying, storage, and processing. These losses account for one-fourth of the overall rice production [25, 27]. According to a study conducted by Malaysian Agriculture Research and Development Institute (MARDI) in 2017, it was found that a loss of approximately 50 kg of rice per five metric tonnes per acre occurs as a result of neglect in both harvesting and post-harvest management.

Subsequently, MADA recorded the highest number of rice farmers experiencing post-harvest management problems, with 70.8% of paddy farmers failing to adhere to proper transport management procedures. The same happens to rice farmers in KADA and IADA-BLS, where 45.8% and 32.0% of rice farmers, respectively, are struggling with post-harvest management issues. The rice farmers did not inspect the transporter for leaks before transporting the rice to the drying complex within 24 h. Moreover, farmers were also not present throughout the rice grading procedure at the mill.

In summary, the sustainability of farm management in the KADA and IADA-BLS regions appears to be higher as compared to the MADA region. The farm management practices in the MADA region are at a possibly unsustainable level. The situation can be attributed to the inadequate adherence to fertilizer, harvest, and post-harvest management procedures among over 50% of paddy farmers in the region, despite the fact that rice cultivation in MADA was initially established before KADA and IADA-BLS.

Determinants of sustainable farm management

Multiple regression analysis was employed to examine the factors influencing sustainable farm management practices among rice farmers. Table 4 presents findings that demonstrate statistically significant and positive associations between the dummy variable of granary area, experience in rice cultivation, making rice the primary occupation, percentage of off-farm income, technology readiness, climate change effects, and machinery ownership with the degree of sustainable farm management practices among rice farmers. According to [28], individuals with extensive experience possess a higher level of proficiency in farm management due to their extensive knowledge base in this domain. The positive effects of off-farm income on sustainable farm management practices signify that greater financial resources enable rice farmers to enhance their information-seeking endeavors and optimize resource utilization. Moreover, Baliyan and Masuku [29] found that an increase in farmers' income levels facilitates their adoption of additional innovations and optimal management practices.

On the other hand, there is a significant negative relationship between age and the level of sustainable farm management among rice producers. This finding aligns with [30], who found that as rice farmers age, the percentage practicing good farm management decreases. Greater farming experience can sometimes make farmers less interested in new agricultural technologies and practices [31, 32]. Additionally, older age does not always equate to greater farming experience, as some farmers begin farming later in life. However, this study's findings contradict [29, 33–35], who reported a positive and significant relationship between age and sustainable farm management practices. Older farmers, with their greater

Table 4 OLS multiple regression analysis of sustainable farm management determinants

Independent variables	Standardized coefficients beta	Std. error	t	Sig
(Constant)	–	4.335	13.778	0.000
KADA	0.175	1.157	3.903	0.000
IADA-BLS	0.283	1.367	6.203	0.000
Age	−0.135	0.043	−2.611	0.009
Experience in paddy cultivation	0.141	0.047	2.669	0.008
Income from paddy production	0.083	0.000	1.764	0.078
Technology Readiness Index	0.102	4.745	2.623	0.009
Percentage of off-farm incomes	0.083	0.002	2.073	0.039
Farmer's perception on impact of climate change on their paddy production	0.093	0.033	2.370	0.018
Institutional factors	0.048	0.030	1.250	0.212
Machinery ownership	0.111	0.383	2.590	0.010
Total area of cultivation	0.004	0.149	0.078	0.938

experience, can be more perceptive and better able to process information [36].

Furthermore, the effect of additional institutional factors and the overall size of cultivated land on the adoption of sustainable farming practices was found to be insignificant. This result contradicts the findings of [18, 19], who reported that participation in extension training courses and extension visits positively influenced the adoption of sustainable farming practices. Previous studies also show varied results; for example, Ahmadpour [18] and Sukayat et al. [20] found that farm size positively and significantly influences the level of sustainable agricultural practices, while [19] found that farm size had a negative effect on the adoption of these practices.

These discrepancies highlight the complexity of factors influencing sustainable farming practices. The mixed results regarding institutional support and farm size suggest that other underlying variables, such as regional differences, access to resources, and individual farmer characteristics, might play significant roles. This highlights the importance of considering a multifaceted approach when designing and implementing agricultural policies, as a one-size-fits-all strategy may not be effective in addressing the diverse needs and circumstances of farmers. It is crucial for policymakers to take into account the varying influences of age, experience, income, and institutional factors to create more effective and supportive frameworks for sustainable agriculture.

The influence of sustainable farming practices on farmer's livelihood

Table 5 shows the estimated effects of sustainable agricultural practices on paddy yield value (RM/hectare). The findings show that each Rice Check component has a distinct effect on paddy production. Seeding management, fertilizing, pest control, and the deployment of transplanters during the planting process, in particular, have positive effects on rice yield. In this study, seeding management refers to the implementation of activities such as: (1) using valid rice seeds certified by the Department of Agriculture; (2) selecting rice varieties based on the suitability of the rice field; (3) using the direct sowing method; 4) soaking the seeds for 24 h after cleaning; (5) executing seed treatment for disease-prone rice varieties; (6) soaked seeds are fermented in an enclosed space for 24–48 h; (7) the paddy field is leveled and saturated with water before planting, and (8) seeds are sown using a sprayer. However, most rice farmers in the IADA-BLS

Table 5 OLS multiple regression analysis of influence of sustainable farm management components on paddy yield

Independent variables	Standardized coefficients	Std. error	t	Sig
Constant		530.992	7.509	0.000
Determination of soil suitability	−0.106	1.695	−2.944	0.003
Rice field design management	0.027	3.223	0.689	0.491
Plowing preparation	0.031	3.431	0.772	0.440
Seeding management	0.080	4.183	2.170	0.030
Fertilizer management	0.097	2.830	2.698	0.007
Water management	−0.033	3.452	−0.847	0.397
Integrated pest management	0.102	3.809	2.542	0.011
Harvesting management	0.032	2.254	0.835	0.404
Post-harvest management	−0.044	3.546	−1.064	0.287
Environmental management	0.000	4.467	0.009	0.993
Transplanter usage	0.226	184.344	6.408	0.000

area do not employ direct sowing, but rather the transplanter method, which eliminates the requirement for processes 3–8. The impact magnitudes of employing a transplanter in rice planting are greater than those of direct sowing, with the transplanter increasing rice yield by 22.6% while direct sowing only increases yield by 8%, as evidenced by the coefficient values of both variables. This result shows that the usage of this transplanter method should be extended to rice farmers in other locations, particularly the MADA and KADA areas, which have a significant number of rice farmers.

The implementation of fertilization management practices, which involve the proper use of the specific type of fertilizer as suggested by the Rice Check Guidelines, tailored to the four distinct stages of paddy growth, has the potential to enhance rice output by around 9.7%. The present findings align with the results reported by [37, 38]. Furthermore, the implementation of integrated pest management (IPM) has a notable favorable impact on rice yields, resulting in a potential increase of 10%. Nevertheless, it has been observed that the practice of assessing the soil's compatibility before to planting has resulted in a reduction of paddy yield by 10.6%. A possible reason for the occurrence is that a substantial number of small-scale farmers may have neglected to conduct soil testing at the beginning of the planting season. This oversight can be attributed to their limited technical knowledge, lack of access to appropriate equipment, and limited opportunities to consult with extension officers for guidance. Consequently, these farmers fail to attain the anticipated maximum potential output.

The study revealed that the factors of paddy field preparation, plow management, water management, harvesting management, and post-harvest management did not have significant effects on the increase of rice paddy revenue. This is due to the fact that all of these parameters are essentially identical among farmers. In the water management component, for example, all farmers in the studied granary area are subject to uniform irrigation plans that are overseen by the granary authorities. Irrigation systems provide a controlled and reliable supply of water to paddy fields, which has several benefits for paddy farming, including consistency of water supply throughout the growing season, reduced risk of drought-related crop failures, the ability to grow multiple crops in a year, and maintaining proper moisture levels, which results in improved crop quality. Reduced vulnerability to climate change: Climate change can bring unpredictable and extreme weather patterns, such as erratic rainfall. Irrigation can help paddy farmers mitigate the impacts of climate change by providing a stable water supply. A similar occurrence is observed in both the stages of crop harvesting and post-harvest management. The process of harvesting is uniform across all farmers, as it involves the utilization of a harvester that is operated by a service provider, which can be either a private entity or a governmental organization. A significant proportion of farmers do not actively participate in the aforementioned activity. The receipt of net income from the rice factory will only occur upon the completion of the entire procedural process.

Conclusions and policy recommendations

Farm management is essential in integrating the use of production inputs in order to increase production levels and farmers' income. Farmers, as producers, must be committed to practicing sustainable farm management by focusing on the process of acquiring farm management skills [39]. Farmers must equip themselves with all good farm management practices in order to tackle the development and changes in agricultural development [40]. Rice Check, introduced by the government, is a guide to assist rice farmers in effectively managing the cultivation of rice. This study investigates the degree of sustainable farm management among rice farmers, its determinants, and its impact on paddy farmers' livelihoods. Overall, the main findings revealed that rice farmers' socio-demographic status is low, and their farm management does not reach the level of sustainable farm management. Age, experience, paddy field area, total household income, and granary area are all key elements determining sustainable farm management among rice farmer.

The key findings demonstrate a negative relationship between age and farm management, indicating that as farmers get older, their level of farm management tends to decline. This implies that it is essential to promote the engagement of youths in the rice-producing industry and ensure the use of efficient and sustainable farming practices. However, it is evident that youths exhibit an obvious lack of excitement when it comes to pursuing a career in the agricultural industry. Therefore, it is crucial to enhance education, training, and awareness programs in order to educate the youth about the significance of agriculture, the potential of paddy farming, as well as the challenges and prospects prevalent in this sector. In order to attract potential youths, it is crucial to prioritize the utilization of information technology and mobile applications within the agricultural sector for the purposes of monitoring crop growth, accessing weather forecasts, and obtaining market-related information. The promotion of agricultural development and youth engagement in agriculture should be prioritized by the government. This can be achieved through the implementation of various schemes and programs. Additionally, it is crucial for the government to acknowledge and celebrate the achievements of young farmers by offering awards and incentives. These measures are essential in inspiring others to pursue agricultural activities and can be further reinforced by showcasing successful youth-led agricultural projects as case studies. This will effectively demonstrate the potential of paddy cultivation and its positive impact on the agricultural sector.

Furthermore, the level of farm management, particularly the components of fertilization management, harvesting management, and post-harvest management, among rice farmers remains unsatisfactory, particularly in the MADA region. In this regard, the relevant organizations must play a role, particularly in terms of guiding, motivating, and encouraging rice farmers to follow the procedures stipulated in the Rice Check manual in order to maximize income. More frequent field monitoring should be implemented to better detect the obstacles that rice producers experience. This is due to the fact that different measures must be followed depending on the suitability and needs of a planting place. Aside from area improvements, technical support and approach should be tailored to the age group, experience of rice farmers, and size of planted rice fields. People with less than 10 years of experience require extra attention and assistance in order to cultivate rice successfully.

Farmers should have a proactive and conscientious approach towards recognizing the importance of implementing sustainable farm management practices. This is attributed to the fact that adhering to the Rice Check technique has the potential to reduce costs, save time, and mitigate the risk of losses. The consideration of planting time and comprehensive management practices can effectively mitigate potential reductions in rice output. It is advisable for farmers to regularly avail themselves of the agency's support in order to enhance the efficacy of their farm management practices.

Abbreviations

IAD-BLS	Integrated Agriculture Development Authority-Barat Laut Selangor
IPM	Integrated pest management
KADA	Kemubu Agriculture Development Authority
MADA	Muda Agriculture Development Authority
MARDI	Malaysian Agriculture Research and Development Institute
OLS	Ordinary lease square
RC	Rice Check
SFM	Sustainable farm management
SFMI	Sustainable Farm Management Index

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Author contributions

RK led the study conceptualization, design, tools development, data analysis and manuscript writing. NNAR contributed to the data collection and descriptive analysis.

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Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interest.

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