BIO Web of Conferences **175**, 02005 (2025) https://doi.org/10.1051/bioconf/202517502005
ISTAKCOS 2024

Analysis of rice cultivation sustainability in rice production centre areas, Indonesia

Dara Intan Salassa[1], *Gecci* Dwi Prasetyo[1,2], and *Syifani* Rizki Noor Syafira[1*]

[1]Koalisi Rakyat untuk Kedaulatan Pangan, Bogor, West Java, Indonesia
[2]Department of Natural Resources and Environmental Management, IPB University, Bogor, West Java, Indonesia

Abstract. Concerns about Indonesia's rice production have led to a focus on sustainable agriculture in agricultural policy. The expansion and development of sustainable rice farming land is still an urgent matter among stakeholders. This study aims to determine the sustainable rice cultivation index and factors that influence the sustainability of rice cultivation in Boyolali, Sragen, Klaten, Madiun, and Ngawi Regencies. The study was analyzed multidimensionally (5 dimensions: environment, economic, social, technology, and institution and policy) using the Multidimensional Scaling-RAPFISH method involving a total of 225 respondents. The results of the study showed that rice cultivation in Central Java and East Java was categorized as quite sustainable, with an average index of 59.85%. This means that, on average, farmers have carried out rice cultivation practices quite well. On average, the use of organic fertilizer, capital, OPT control, work safety instructions, and farmer participation in farmer groups are the factors that most influence sustainable rice cultivation. This study emphasizes the importance of sustainable rice cultivation practices, as well as the involvement of all stakeholders in increasing the capacity of farmer groups, extension workers, and business partners, as well as providing incentives, in the form of organic fertilizer subsidies, capital, and training.

1 Introduction

Rice has been one of the strategic food commodities that is prioritized by Indonesia's national development program. According to the 2024 National Socio-Economic Survey (SUSENAS), the consumption rate of rice reached 98.92%, indicating that the majority of households in Indonesia consume rice as their staple food. Indonesia’s rice consumption is predicted to increase by 1.5% each year, reaching up to approximately 99.08 kg per capita in 2025 and continuing to increase gradually by 2%, reaching up to 99.5 kg per capita in 2045 [1]. Thus, national rice consumption in 2045 is projected to be 41.7 million tons in total. However, in contrast, the production sector of rice in Indonesia is feared to decline with various factors affecting it, such as land-use change, land degradation, inadequate rice policy governance, and climate change [2- 4].

* Corresponding author: rira@kedaulatanpangan.org

Indonesia is one of the countries that is hugely affected by the impact of climate change, mainly on the food and agriculture sectors. One of the concerns that has been the main focus of the government is food security, generating policies and innovations with the purpose of maximizing rice production at the cost of exploiting the limited natural resources, which causes environmental damage. On the other hand, the agriculture sector is not only affected but also contributes to the increase in gas emission rate. Rice cultivation is generally known to require a high volume of water; however, amid the climate crisis, water availability has become limited. Previous studies have shown that continuous flooding in rice fields is the main cause of the increase in methane gas emissions. It is reported that farmers with irrigated rice fields, which is a popular rice cultivation method in Asia, use on average 25-30% more water than required. Those numbers contribute to 44% of the total agriculture CH^4 emission and 88% of the total rice cultivation CH^4 emission. With rice production as one of its main agricultural productions, Indonesia is claimed to be the third Asian country in terms of the highest greenhouse gas emission contributor after China and India [5-7]. Therefore, by excessively irrigating the rice field, in addition to the application of chemical fertilizer and pesticides, rice cultivation has not only been impacted by climate change, but also contributed to the increase in gas emission rate.

Several problems occur during the rice cultivation process, resulting in various actions needed to overcome these problems. One of the actions would be encouraging the practice of sustainable rice cultivation methods as a movement that could be started from the grassroots level. Sustainable rice cultivation is also known by terminologies such as organic agriculture, natural agriculture, and eco-friendly agriculture, which fundamentally have the same principles emphasizing environmental sustainability and nutritious and safe food production. However, existing agriculture practices have not fully guaranteed the environmental, economic, and social aspects. Several studies showed that while organic rice farming in Indonesia demonstrates the highest sustainability index, the overall ranking of rice cultivation practices reveals significant shortcomings, particularly in non-organic methods, highlighting a broader issue of insufficient sustainable agricultural practice in the region [8, 9]. One of the highlighted factors was the lack of regulation on sustainable practices and good agricultural practices of rice production in Indonesia. As of 2024, Indonesia does not have a guideline that specifically regulates sustainable rice.

Internationally, regulations on sustainable agriculture have been implemented in several commodities, such as coffee and palm oil. On rice production, initiatives such as the Sustainable Rice Platform (SRP) are being implemented as an effort to reduce carbon emissions and other impacts towards climate change while ensuring the welfare of farmers. Sustainable Rice Platform (SRP) is a sustainable rice cultivation standard covering regulations from the pre-planting phase until post-harvest. The standard also includes guidelines for farm management, labour practices, and the health and safety of farmer labourers [10]. In order to adopt such a regulation in Indonesia, research must be done to contextualize the SRP regulation accordingly. Therefore, understanding the sustainability level of rice cultivation practices that are used by Indonesian farmers, especially in the centre of rice production regions such as East and Central Java, is needed to construct a better-suited sustainable rice regulation. Using MDS/RAPS analysis, this research was done to analyse the sustainability level by measuring the score of each variable of sustainability, such as environmental, social, and economic aspects of rice production. MDS-RAPS offers flexible measurement, allowing researchers to modify dimensions, attributes, and scoring to suit the needs and relevance of the study area's conditions [11]. The consideration for selecting MDS/RAPS is based on its multidimensional nature, with dimensions and attributes that can be independently tailored to align with the specific goals and local context of the study. This distinguishes it from other sustainability evaluation tools, such as LCA, which primarily focuses on environmental dimensions. This study aims to determine the sustainable rice cultivation index and the factors that influence the sustainability of rice farming in Central Java and East Java.

2 Research Method

2.1 Study location

Research was done in five districts located in Central and East Java, which are Klaten, Boyolali, Sragen, Ngawi, and Madiun Districts. All five districts are part of the main centre of rice cultivation in Indonesia. As the central area of rice production, there would be found various methods of rice cultivation that enable researchers to identify whether rice cultivation standards are in accordance with the principles of sustainable agriculture. Data was collected from April 1st to May 14th, 2024.

2.2 Sampling and informants

The sampling technique employed in this study is snowball sampling, selected due to the limited availability of population data within the research area. Despite this limitation, the sample size remains appropriate and consistent with the requirements of the MDS-Raps (Multidimensional Scaling – Rapid Appraisal for Sustainability) method. In the MDS-Raps framework, sampling is categorized into two groups: rice farmers, who serve as respondents for data collection through questionnaires, and expert informants, who provide insights via in-depth interviews. Regarding the sample size of public respondents, the MDS-Raps method does not require a specific number of data points, as it utilizes a non-parametric statistical approach. Consequently, classical statistical assumptions are not mandatory. Nonetheless, the data must still fulfil essential quality criteria to ensure reliability—namely, objectivity, relevance, representativeness, timeliness, and a low sampling error.

In this study, the number of main respondents was 30 rice farmer respondents per district, while expert informants were 15 respondents per district, a total of 225 respondents. The criteria for rice farmer respondents are: 1) Respondents who are active farmers with private land ownership or land rental status; and 2) Farmer respondents who do rice cultivation using technical irrigation systems or semi-technical irrigation. Meanwhile, respondents using in-depth interview techniques were respondents from farmer group administrators, small rice mill owners, agricultural services in the cultivation sector, public works services for water resource management, field agricultural instructors, POPT, financial institutions, rice traders, and input distributors.

2.3 Data Collection

The data collected in this research consists of primary data and secondary data. Primary data was obtained through questionnaire interviews and in-depth interviews. Data collected through questionnaire interviews is related to standard rice and rice cultivation practices at the farmer level, which are measured through 5 dimensions of sustainability, namely environmental, economic, social, technological, and institutional. In detail, the measurement attributes of each sustainability dimension are shown in Table 1. During in-depth interviews, data related to the situation and conditions of rice supply chain actors, challenges, constraints, and opportunities were collected. Meanwhile, secondary data were obtained from the village government, food security service, and agriculture service. The data collected includes village and district policy data that is still relevant to paddy and rice cultivation standards in regencies.

2.4 Questionnaire test, validity, and reliability of data

Following the development of the questionnaire, the next step was to conduct a pretest with prospective respondents. This pre-test aimed to ensure that the questionnaire was comprehensible to the target audience, as indicated by the clarity of their responses. The purpose of this testing phase was to produce a questionnaire that is easy to understand, relevant to the research objectives, and appropriate for the context of the study area. The pre-test involved two rice farmer respondents and two experts in sustainable rice agriculture. Meanwhile, the validity and reliability of the data were assessed using the Rapfish software, which includes evaluations through Monte Carlo scatter plots, stress values, and R^2 indicators. The Monte Carlo scatter plot is evaluated by comparing the differences in values between the Rapfish ordination and the Monte Carlo results. The maximum acceptable difference is 5%, which indicates that the model is considered adequate for estimating the sustainability index/status. The stress value is used to indicate discrepancies or misfit (a lack of measurement). The evaluation of the stress value suggests that the closer the value is to 0, the more closely the output aligns with the actual conditions. The R^2 value represents the proportion of data variance that can be explained by the model. The closer the R^2 value is to 1, the better the model is at explaining the data variance, indicating a mor*e* accurate representation. In detail, Table 1 presents the attributes tested in the study.

Table 1. Dimensions and attributes to measure the sustainability index of rice cultivation.

Dimensions	Attributes	References
Ecology	Land conversion	RIKOLTO; Kyle *et al* (2023)
	Planting pattern	Kyle *et al* (2023)
	Use of good-quality seed	RIKOLTO
	Fertilizer and pesticide procurement	KRKP (2019)
	Use of organic fertilizer	KRKP (2019)
	Water irrigation source	Hanipah *et al* (2020)
	Irrigation network condition	Hanipah *et al* (2020)
	Industrial waste pollution	RIKOLTO; Faridz *et al* (2021)
	Rice stubble handling	RIKOLTO
	Rice straw handling	RIKOLTO
Economic	Financial eligibility	Nurmalina (2008); Faridz *et al* (2021); Barchia *at al* (2021)
	Profit rate	Nurmalina (2008); Faridz *et al* (2021)
	Farm-gate price of unhusked rice	Faridz *et al* (2021)
	Changes in the real wages of agricultural labourers	Nurmalina (2008)
	Retail price of rice	Nurmalina (2008); Barchia *at al* (2021)
	Payment mechanism	KRKP (2019)
	Capital	Faridz *et al* (2021)
	Non-agriculture family income	Faridz *et al*(2021)
	Crop harvest management (harvest period)	RIKOLTO
	Post-harvest management (drying period)	Santoso *et al* (2023)
Social	Farmer's age	KRKP (2019)
	Local wisdom	KRKP (2019); Barchia *at al* (2021)
	Farmer groups' activeness	Santoso *et al* (2023
	Price information accessibility	KKRP (2019)
	Consumption growth per capita	Nurmalina (2008)
	Socialization of safety and first aid instruction	RIKOLTO

Dimensions	Attributes	References
	Compliance with the abolition of forced labor	RIKOLTO
	Compliance with workers' wage	RIKOLTO
	Child labor	RIKOLTO
	Child education	RIKOLTO
Technology	Planting system	RIKOLTO
	Seed preparation techniques	RIKOLTO
	Soil processing technology	Santoso *et al* (2023)
	Irrigation technique	RIKOLTO
	Pest management	Santoso *et al* (2023)
	Personal protective equipment utilization	RIKOLTO
	Harvest technology	Barchia *at al* (2021)
	Drying technique	RIKOLTO
	Waste management technology	KRKP (2019)
	Marketing technology	Krishnankutty *et al* (2021)
Policy and Institutional	Farmer regeneration government program	KRKP (2019)
	Government subsidy for fertilizer	Barchia *at al* (2021)
	Farmer group institution	Santoso *et al* (2023); Irianto *et al* (2023)
	Farmer group participation	Khaerunnisa (2023); Rachman *et al* (2022)
	Presence of an agriculture extension officer	Barchia *at al* (2021); Santoso (2023)
	Participation in outreach activities	Rachman *et al* (2022)
	Presence of KUD/BUMDES	Nurmalina (2008)
	Finance institution accessibility	Faridz *et al* (2021)
	Partnerships	Faridz *et al* (2021)
	Conflict between farmer groups	Santoso (2023)

2.5 Data Analysis

The data that has been input will go through a data processing process using Rapfish (Rap) software via the multidimensional scaling (MDS) method to assess the sustainability index of implementing rice cultivation standards. Raps Analysis (Rapid Appraisal for Sustainability) is a rapid assessment technique for evaluating sustainability and one of the tools to support policy making. The term "Raps" is used as a replacement for "Rapfish," which originally stemmed from its development and was specifically associated with sustainability evaluation in the fisheries sector. To avoid confusion due to the proliferation of terms such as "Rapfish," "Rapfarm," and others, the name "Raph" was chosen as a solution, aligning with the growing trend of multidisciplinary research aimed at evaluating sustainability levels [11].

Rice cultivation sustainability index research required a multivariate sustainable analysis. Therefore, the MDS-Raps analysis was chosen over other analytical tools. MDS-Raps offers flexible measurements, allowing researchers to modify dimensions, attributes, and scoring according to the needs and relevance to the study area's conditions. Additionally, its easily interpretable output visualization, quick operation, and relatively simple usability further enhance the advantages of this analysis.

The stages of the MDS-Raps analysis begin with: (1) defining the focus of the study and the unit of analysis, (2) determining the dimensions of the study based on previous research findings and sustainable development theory, (3) identifying the attributes for each sustainability dimension, (4) developing a scoring system (bad-good) for each attribute, (5) inputting the research results' values/scores for each attribute into the Rapfish software, and (6) constructing the reference matrix and anchor matrix, (7) Adjusting the software template to align with the study unit, (8) running the Rap analysis (sustainability index) to determine the sustainability percentage of each dimension. The sustainability categories based on the sustainability ordination index for rice cultivation are shown in Table 2. (9) Running leverage to obtain the leverage of attributes, which identifies the dominant attributes influencing each dimension. Dominant attributes are those that are sensitive to changes in the sustainability index. The higher the RMS (root mean square) value of an attribute, the greater its sensitivity. (10) Running Monte Carlo with a 95% confidence interval to assess the influence of errors and enhance the confidence in the model. (11) Validating the model based on the squared correlation (R^2) value and the Stress value. Finally, (12) constructing a trade-off diagram, specifically creating a kite-shaped diagram to observe the trade-offs based on the study dimensions.

Table 2. Sustainability categories are based on the sustainability ordination index value.

Index score	Category	Description
0.00 – 25.00	Poor	Unsustainable
25.01 – 50.00	Below average	Less Sustainable
50.01 – 75.00	Adequate	Moderately Sustainable
75.01 – 100.00	Good	Sustainable

Through this analytical approach, a clear and comprehensive picture of the sustainability level of rice cultivation and the sensitive attributes affecting sustainability changes across the five study areas is obtained. This, in turn, can be used as a basis for formulating appropriate policy recommendations for the government to achieve the development of sustainable rice farming areas, as well as providing input for the development of the National Interpretation Guidelines for SRP (Sustainable Rice Platform) in the Indonesian context at the National Working Group (NWG) forum in Indonesia.

3 Respondent characteristics

3.1 Age of rice farmers

Farmers' age classification, in accordance with the agriculture survey of BPS-Statistics Indonesia, is categorized into two categories: millennial farmers (age 19-39 years old) and elder farmers (over 39 years old). The population of respondents is made up of 95% elderly farmers, with the oldest respondent being 87 years old, and 5% of millennial farmers. This indicates that the rice production center area has a low rate of farmer regeneration, which influences the adoption rate of agricultural technology and work productivity.

3.2 Land holding area

Sixty percent of respondents are reported to be small-scale farmers with ownership of 0.05 to 0.49 hectares of land. Moreover, 38% of small-scale farmers are also reported to be farmers with rented land. The large number of small-scale farmers indicates an increasingly narrow agricultural land, as well as other problems and obstacles that can affect farmers' welfare and food security. Farmers' income tends to be low and often can't cover the production cost, hence resulting in an increasingly low rate of farmers' welfare.

3.3 Farming experience

Sixty seven percent of respondents are experienced farmers with 10 years of experience, indicating that farmers have become accustomed to rice cultivation and tend to use more traditional cultivation methods compared to less experienced and younger farmers. This also implies difficulty for agriculture field instructors in introducing new agricultural technology innovations to elder farmers due to potential resistance to new cultivation methods.

4 Results and discussion

4.1 Leverages of attributes of rice cultivation sustainability

4.1.1 Environment dimension

The leverage of attribute analysis shows the results of attributes that have the highest sensitivity to changes in the sustainability of rice cultivation practices across the five study locations. In this study, out of the 10 environmental dimension attributes tested, 3 attributes with the highest root mean square (RMS) values (high sensitivity) were selected for each study area (Figure 1). Industrial waste contamination emerged as a significant factor influencing the sustainability of rice cultivation, as indicated by all five study locations, each showing it as one of the top three attributes with the highest RMS values. In Klaten and Ngawi regencies, industrial waste contamination became the dominant attribute that most affected the sustainability status in these areas. The presence of industrial waste contamination can impact the sustainability of rice cultivation, making it crucial to identify rice farming areas free from industrial waste contamination [10].

The findings indicate that the rice farming areas in the study locations are free from industrial waste contamination due to the distance between the rice fields and industrial or factory sites. Additionally, the policy regulation establishing protected rice land (LSD) supports investment quality and the enforcement of land rights (HAT) by local governments in the study areas. Although all study locations are free from industrial waste contamination, other factors, such as the use of chemical fertilizers and pesticides, need to be minimized. This is because fertilizer use affects the sustainability of rice cultivation [12].

The analysis findings indicate that the use of organic fertilizers in Boyolali and Sragen regencies is a dominant attribute influencing sustainability. This is due to the high usage of chemical fertilizers, particularly among farmers in Sragen, making the application of organic fertilizers crucial. The use of organic fertilizers helps prevent soil degradation, which leads to the loss of nutrients and organic matter, and improves soil retention properties, thereby protecting plants from dehydration [12].

The use of high-quality rice seeds is a determining factor for sustainable rice cultivation, as it directly impacts production yields [13]. In Madiun Regency, the attribute of using quality seeds shows high sensitivity to sustainability in the area. To date, most farmers in Madiun purchase certified seeds from agricultural stores, while also considering local wisdom and limiting seed usage to three planting cycles. Additionally, farmers receive certified seed assistance from the Madiun Agricultural Office. Irrigation water sources and the condition of the irrigation network significantly influence sustainable rice cultivation. This is reflected in the high RMS values in Klaten, Sragen, Ngawi, and Madiun regencies. The poor condition and functionality of the irrigation network can hinder the smooth distribution of water in irrigated areas [14]. Based on the findings, the irrigation network conditions in Madiun and Ngawi regencies are generally poor, although they are still functional in delivering irrigation water, albeit with low flow rates.

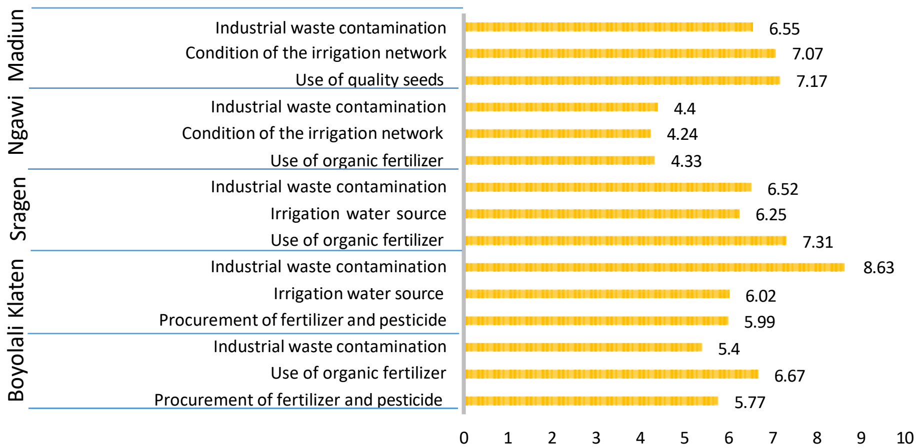

Fig. 1. Leverage analysis of the environmental dimensions of rice cultivation sustainability

4.1.2 Economic dimension

Capital has high sensitivity to sustainability across all five study locations. Capital is a crucial aspect of running a business. However, farmers often face limitations in personal capital and rely on minimal loans. In Sragen Regency, capital has the highest sensitivity compared to the other regencies. The findings show that farmers do not access financial institutions, either due to a lack of access or reluctance to get involved.

There have been no significant changes in the real wages of agricultural laborers across the study areas. A shortage of laborers often occurs during the harvest season. The lack of harvest workers leads to an increase in labor wages. Changes in the real wages of agricultural laborers are one of the factors influencing the sustainability of rice cultivation practices [15]. Wages that are relatively low or not commensurate with the hard work performed can affect agricultural laborers' intention to work in the rice farming sector. As a result, the labor force in rice farming declines. Given its influence, wage systems should be closely monitored, ensuring fairness, which in turn can positively impact laborers' interest in working in the sector. Other attributes that influence sustainability include non-agricultural household income, rice retail prices, and payment mechanisms.

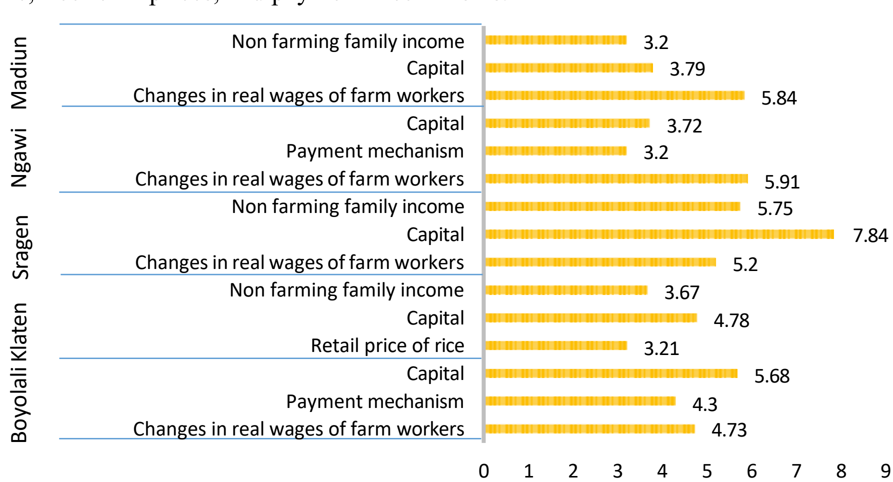

Fig. 2. Leverage analysis of economic dimensions of rice cultivation sustainability

4.1.3 Social dimension

Based on the leverage analysis diagram, the social dimension indicates that occupational health and safety instruction and growth in per capita consumption are attributes with sensitivity across all study areas. (Include journal information about this). From this data, it can be concluded that occupational health and safety instruction and growth in per capita consumption are factors that influence the sustainability of rice cultivation in the five sample areas.

Occupational health and safety instruction is closely related to all aspects of farmers' activities, which often involve hazardous chemicals (B3), such as pesticides. The World Health Organization (WHO) reports that 355,000 people suffer from pesticide poisoning each year, with many cases resulting in death [16]. The high risks associated with rice cultivation necessitate the provision of health and safety instructions for farmers. These instructions are intended to ensure the continued viability of rice farming operations. In the five sample areas, the average farmer does not receive any health and safety instructions or advisories. The vast agricultural land and large number of farmers have not yet led to adequate attention being given to workplace health and safety (K3) protections for agricultural workers [17].The research findings in the sample areas do not align with the attribute of occupational health and safety instruction, which highlights the importance of health and safety advisories for the sustainability of rice cultivation.

In the sample areas, growth in per capita consumption does not have the highest average value, but it emerges as one of the top three important attributes for the sustainability of rice cultivation in all the sample areas. A high growth in per capita consumption indicates an increase in consumption values among the population. One of the main consumption expenditures of the population is on staple food items. Rice is one of the largest staple foods worldwide. A total of 26 densely populated countries, including China, India, and Indonesia, have rice as their staple food. The high consumption of rice as a staple food among the population leads to an increase in market demand. This growth in demand becomes a crucial factor influencing the sustainability of existing rice farming operations.

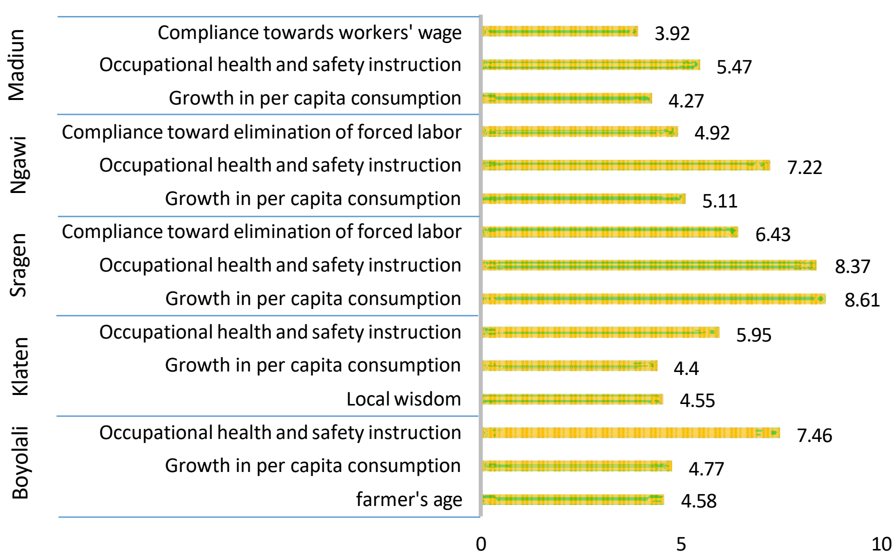

Fig. 3. Leverage analysis of the social dimensions of rice cultivation sustainability

4.1.4 Technology dimension

The use of personal protective equipment while working in agricultural areas is a sensitive attribute in all four research locations (Figure 4). The use of personal protective equipment (PPE) in Boyolali Regency is the highest among other technology dimension attributes. However, compared to Klaten Regency, the attribute of PPE use has a higher RMS value even though it is in second place in the Klaten area analysis. The results of the PPE analysis reflect the importance of its existence as a supporter of increasing the sustainability of rice cultivation because of the importance of farmer health. However, the use of PPE is actually less noticed by farmers. Most agricultural actors and producers, especially in developing countries, do not wear PPE when working with pesticides, especially gloves, glasses, and aprons [18]. This lack of attention is due to the economic status that makes it difficult for farmers to buy quality and complete PPE. And thermal discomfort is the main reason why many farmers and agricultural workers choose not to wear protective equipment [19]. The AWD irrigation technique is another sensitive attribute that can influence the improvement of rice cultivation sustainability if implemented and handled properly. In line with previous research, AWD has a significant impact on water efficiency in rice cultivation, thus affecting sustainability [20]. Demonstrations and training courses conducted in Asian countries consistently show that AWD can reduce irrigation water use by up to 29% without significantly affecting crop yields [21].

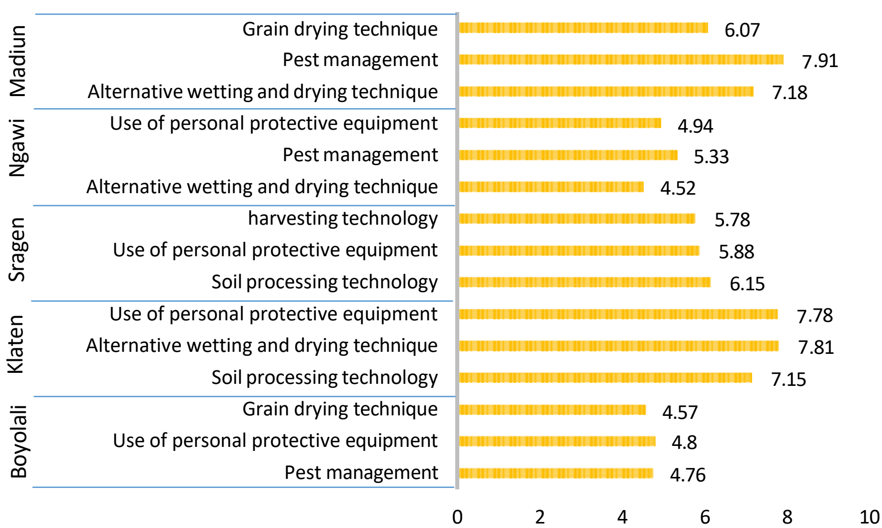

Fig. 4. Leverage analysis of technology dimensions of rice cultivation sustainability

4.1.5 Institutional and policy dimension

The existence of farmer cooperatives has high sensitivity, especially in Ngawi Regency (RMS = 7.49), which means that this attribute has an influence on determining the sustainability of rice cultivation in Ngawi Regency. Meanwhile, the existence of farmer cooperatives in Ngawi Regency is quite passive in its activities. Even if there are cooperatives operating, their role in supporting the fulfillment of agricultural needs is still very limited and small-scale. This is in line with previous research, that the lack of farmer cooperatives in Lubuk Bayas Village, North Sumatra, results in farmers having difficulty obtaining agricultural production facilities and capital problems [22]. The existence of cooperatives is very important in supporting sustainable rice farming, because it helps farmers in providing agricultural credit, agricultural inputs, arranging product storage, to marketing [23].

The existence of farmer groups is a sensitive attribute that affects sustainability, especially in Sragen Regency with the highest RMS value compared to Ngawi and Boyolali Regencies. Even so, these results still mean that in the three regencies, sustainable rice cultivation practices in the institutional dimension are equally supported by the attribute of the existence of farmer groups. For this reason, it is important that farmer groups can stand and run actively along the location where rice farmers live. Farmer groups need to be empowered to become strategic coordination centers for farmers and related parties (financial institutions, government, educational, and knowledge institutions). With the empowerment of farmer groups, synergy between various parties will be created well and become an important step in supporting sustainable agriculture [24].

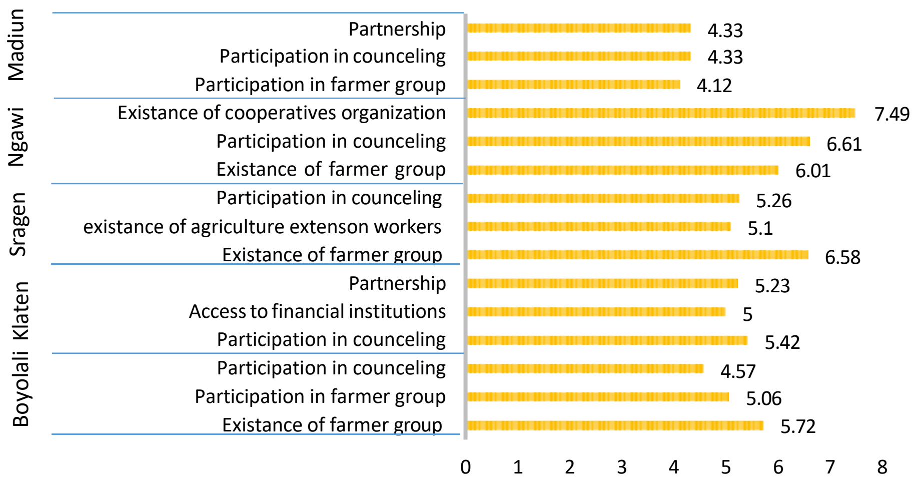

Fig. 5. Leverage analysis of the social dimensions of rice cultivation sustainability

Monte-Carlo analysis results show that, on average, Central and East Java have a stress value of 15%, which is close to the number of 0%, indicating that the data used is close to the real situation in the field. The average of the R^2 value is also shown to be close to the ideal value, which indicates that data variants are well-explained by the model used in the analysis. Based on the two statistical parameters, it is concluded that every attribute used in all dimensions is able to illustrate the statistical parameter well in rice cultivation in the five districts.

Table 3. Monte-Carlo analysis result and statistical parameter value of rice cultivation sustainability index in Central and East Java

District	MDS	Monte Carlo	Difference	R^2	Stress Value	Stress Category
Central Java						
Boyolali	57.11	56.66	0.45	0.92	15%	Moderate
Klaten	64.91	63.71	1.2	0.92	14%	Moderate
Sragen	52.44	52,25	0.19	0.90	15%	Moderate
East Java						
Ngawi	60.46	59.87	0.59	0.92	15%	Moderate
Madiun	62.61	61.77	0.84	0.90	15%	Moderate

 https://doi.org/10.1051/bioconf/202517502005

Monte-Carlo analysis results reported a small difference of 0.59% between MDS and the Monte-Carlo sustainable index value, with a confidence interval score of 95%. This implies that the model is considered adequate to predict the sustainability status or index.

4.2 Rice cultivation sustainability index in the rice production central area

Rapfish analysis results show that rice cultivation in Central and East Java has a sustainability index of 58.15% and 61.54%, respectively. The average of the sustainability index of all districts is 59.85%, indicating that the rice cultivation method used in all five districts has been quite sustainable. As shown in Figure 2, at least four dimensions of the sustainability index—economy, social, institutional and policy, and ecology—in all districts have shown a good result, while the technology dimension is still reported to be the least sustainable.

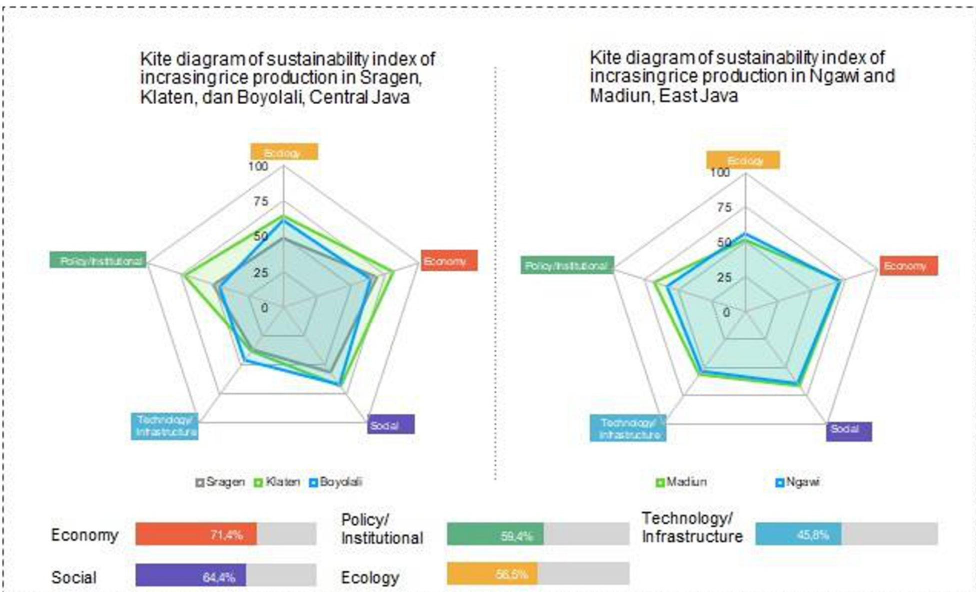

Fig. 6. Rice cultivation sustainability index in the rice production central area

The kite graph on sustainable rice production in Central Java shows that the green line (Klaten) has a wider range than the other lines, indicating that the average value of the sustainability index of rice cultivation in Klaten Regency is higher. On the other hand, the kite graph on rice production in East Java shows that between the green (Madiun) and blue (Ngawi) lines, the wide range is almost similar, but the difference in distance is quite visible in the institutional-policy and environmental dimensions. The five dimensions of sustainability influence changes in the sustainability index in each research area.

To the ideal sustainable index of rice cultivation standard practice in Boyolali, Klaten, Sragen, Ngawi, and Madiun districts, intervention through governance improvement is urgently needed, especially in the least ideal dimensions. Economic dimension, as the support for increased sustainability, is shown to have an obstacle in the financial capital aspect. Findings show that access to financial capital is significantly affecting the sustainability of rice cultivation, mainly in Sragen, Klaten, and Boyolali districts. The majority of farmers are reported to have limited access to agricultural capital. Most of them use their personal savings for the capital of their rice business, and only a small number of farmers have access to financial institutions for assistance. Limited access to financial aid for farmers is due to small land and uncertified land ownership. This is supported by BPS-Statistics, data which reported that small-scale farmers (68%) dominate the number of farmers in the Sragen district [5]. Farmers are reported to face difficulty in accessing capital, especially in the fulfillment of collateral requirements. Credit programs such as *Kredit Usaha Rakyat* (KUR) are offered by the government, however, only 15% of crop farmers in the Sragen district are listed as clients of said program. Problems in accessing capital are obstructing farmers from accessing good-quality agricultural inputs and adopting new agricultural technology.

In East Java, analysis shows that the price of grain and the income of farmers have the highest effect on the sustainability of their economy. In 2024, the price of grain increased by 4.86% for dry grain and 33.48% for milled dry grain, compared to the previous year [6]. The price index received by farmers tends to fluctuate in 2021-2023. Fluctuation is also influenced by the rice planting phase; the lowest price is usually obtained by farmers in the harvest period due to the increase in production. However, an increase in production does not significantly affect farmers' financial ability to cover the production cost, including increased labor wages. This implies that there is no exponential correlation between the increase in farmers' wages and the life quality of farmers. Statistical data also shows that the rural farmer's wage in 2022 was below the district's minimum wage rate, even though the farmer works almost every day in a month. Low farmer income can influence the disinterest in farmer labor work in the rice agriculture sector, which could result in an even lower number of farm laborers amid high demand for human resources. An intervention through wage system governance is urgently needed to overcome this concerning situation.

The social dimension is facing problems, especially in terms of farmer regeneration, consumption per capita growth, and agriculture consultation and supervision in a health and safety context. In some areas, the number of millennials participating in agriculture has been a benchmark used by the government to measure the success of farmer regeneration programs. BPS-Statistics Indonesia of Boyolali district (2023) reported that out of 159,861 farmers registered in Boyolali, only 12.47% of them are millennial farmers (age 19 – 39 years old) [7]. This illustrates that the farmer regeneration program in Boyolali is not going as well as expected. In order to encourage young farmers' interest in agriculture, incentive policy and government regulation are needed to support the young farmers, especially concerning financial, education, skill, technology, and market aspects. In developing countries with limited capital budgets, support for young farmers is provided in other forms of support, such as in Africa, the Tanzanian government provides tax relief on the purchase of agricultural tools and machinery, as well as the enactment of laws that protect young people from land rental discrimination [28, 29]. Based on this, farmer regeneration specifically needs to be considered because it is part of the sustainability of farming businesses.

Another problem found in the social dimension of rice cultivation is the low participation in occupational health and safety instruction for farmers. Agricultural activities have a high risk of hazard and are the third highest in terms of the number of accidents in 2019 – 2021 [25]. The policy regarding occupational health and safety in agriculture, regulated by the government, is only focused on the use of pesticides. On the other hand, other risks, such as machinery and equipment usage, have not been considered. The role of an agriculture field consultant is significantly needed to not only give consultation on cultivation techniques but also instruction on the usage of protective equipment. Lack of awareness of the need to use protective equipment is also an obstacle found in the technology dimension. However, a previous study found that there is a positive correlation between the usage of protection equipment to the comfort of farmers during work hours, yet farmers are not compliant with wearing it every day [26]. Hence, an agriculture field consultant's role is crucial in educating farmers on the importance of occupational health and safety standards, especially protective equipment usage.

Research also found that the growth of food consumption is gradually increasing and yet one district faces a problem of rice supply deficit in 2023. This situation has an effect on the sustainability status of people's needs for rice as demand for rice starts to rise, pushing farmers to increase production. However, increasing production without sustainable cultivation practices would increase the risk of natural resource exploitation, soil degradation, and damage to the ecosystem, which would lead to lower life quality for everyone, even farmers. A farmer's life is found to be strongly related to the condition of the surrounding environment. A healthy environment will contribute to physical and mental health. Based on the data gathered from the five districts, it is emphasized to promote the use of organic fertilizer and pesticides, solving the industrial waste contamination, and more well-managed irrigation water sources and networks to ensure the quality of the environment.

Industrial waste contamination is mentioned to be one of the influential attributes on the practice of sustainable rice cultivation in all of the districts. While there is no report of contamination from industrial waste, contamination from chemical fertilizers and pesticides is the main concern for rice cultivation. Soil fertility level gradually declines as one of the impacts of excessive chemical substance application. It is also reported that exposure to chemical substances is damaging the health of farmers due to the negligence of wearing protective equipment such as gloves, masks, boots, and appropriate clothes during the application of chemical fertilizers and pesticides.

Fertilizer application is also one of the influential attributes that has a significant role in achieving the sustainability status in the rice cultivation standard. On average. Farmers in all five districts use semi-organic cultivation methods and are gradually transforming to fully adopt the organic method. Such actions are fully supported by their respective local government. In Ngawi district, the sustainable, eco-friendly agriculture program *Pertanian Ramah Lingkungan Berkelanjutan* (PRLB) has become one of the supports given by the regent in the form of organic agriculture training with an organic certification institution. Increasing focus on the support of organic agriculture would encourage more farmers to apply more sustainable rice cultivation standards.

Increasing support for farmers on technology and new innovation is also important to fully encourage farmers in doing a more effective and efficient cultivation, yet still focusing on the preservation of the environment and sustainability of their social and economic aspects of life. In terms of rice cultivation technology, the majority of farmers are adopting modern and simple technology, such as tractors for soil tilling and other simple tools for the next step of cultivation. It is a good method to use as it helps to preserve the land quality, is good for plant growth, and farmers are expected to keep adopting this method for a more sustainable rice cultivation. Other technology that needs to be the focus of the sustainable cultivation standard is pest management. The majority of farmers reported that rodent pest attacks have become more frequent and damage their crop, resulting in a 50% drop in rice production every harvest season. Farmers are currently using stun traps or rodenticide, as these are claimed to be the most effective way to manage rodent pests. However, stun traps and rodenticides are not only harming rodents but also have a high probability of harming the safety of humans, and the implementation of those methods violates the Sustainable Agriculture System Law under Article 50, paragraph 1, Law No. 2022 of 2011. Adapting natural pest management technology, such as utilizing natural enemies for rodents—snake and owl— should be the solution to minimize the contamination and work accidents risk, yet said contamination is the reason for the lack of natural population for snakes and owls around the rice field anymore. This supports the rapfish analysis that shows pest management has a crucial role in achieving sustainable cultivation practices, and the government should put more focus on intervention for handling problems that arise from this aspect.

Agriculture is also dependent on the water irrigation system for good production. The majority of farmers in the Sragen district use an irrigated agriculture system, which is a popular method in Asian countries and also widely used in most areas in Indonesia. A more ideal irrigation system that fits the cultivation culture in Indonesia and is also best for the sustainability of the environment is the alternate wetting-drying (AWD) method. AWD irrigation method is an irrigation practice that only floods the rice field up to the root zone of the crops, using much less water than the more adapted method of cultivation. Research found that only 37% of farmers have used this method, as others claimed that adaptation of AWD irrigation would only worsen the growth of weeds and would cost farmers more for weeding labor wages. Previous studies show that exposure of the soil surface due to low volume of water in its early drying phase would increase the aeration and increase weed growth [27], but would not encourage growth of weed growth when applied under 50-60% canopy coverage. Overall, the AWD method is a climate-smart farming solution and suitable for farmers to adopt, however, institutional support is needed to increase the adoption rate of this method.

The existence of farmers' groups and the participation of farmers in said groups are important aspects in the institutional and policy dimension and are affecting the sustainability of rice cultivation. Participation in the farmer groups enables farmers to receive support in capacity improvement, including the adoption of technology and innovation. The importance of the existence of a farmer group is not physical, but it is seen from the function and benefits that farmers get, collectively and individually. Shaping farmers' positive perception on organic-based input can also be conducted through the farmer group, and education of organic farming does not stop at the usage of organic-based input but also the procurement method that is done independently as research found that farmers are still partly using chemical-based input and is also facing difficulty in retrieving fertilizer. Previous research found that difficulty in obtaining fertilizer was experienced by the farmers of the Gondang area in Sragen when the government allocated less subsidized fertilizer by more than 50%. Expecting the rise in production to rise but not supported by the supply of subsidized fertilizer would be a constraint for farmers, as they need to spend more on production costs with more expensive fertilizer. The large encouragement for the use of chemical inputs and the difficulties of farmers in financing farming influence the level of sustainability, both from an environmental perspective and farmers' economic income.

5 Conclusion

Overall, the standards for sustainable rice cultivation, both in Central Java and East Java provinces, show that all districts have achieved a sustainability index with a moderately sustainable status. In almost five districts, the economic dimension achieved the highest index compared to other dimensions. Meanwhile, the technological dimension often occupies the lowest position compared to other dimensions. Even though overall it has achieved a fairly sustainable index, many improvements are still needed in the aspects that support sustainability. The attributes that have the most significant influence on the sustainability of rice cultivation in rice production centers in each districts include: Boyolali (use of organic fertilizer, capital, occupational health and safety instruction, use of personal protective equipment, dan extance if farmer group), Klaten (industrial waste contamination, capital, occupational health and safety instruction, alternative wetting and drying technique, and participation in counceling), Sragen (use of organic fertilizer, capital, growth in per capita consumption, soil processing technology, and existence in farmer group), Ngawi (industrial waste contamination, changes in real wages of farm workers, occupational health and safety instruction, pest management, and existence of cooperatives organization), Madiun (use of quality seeds, changes in real wages of farm workers, occupational health and safety instruction, pest management, and partnership-participation in counceling).

Recommendations that can be suggested based on the condition of rice farming in each district, including: Boyolali Regency: 1) building a cooperation model between farmers and business partners based on mutual benefit and strengthening, and 2) increasing assistance from agricultural extension workers in providing training to assisted farmers. Klaten Regency: 1) implementing environmentally friendly agriculture through the provision of agricultural land and maximizing regulations on protected rice fields, 2) increasing access to capital and its convenience, especially for small farmers, 3) capacity building programs for the entire rice and paddy value chain. Sragen Regency: 1) increasing environmentally friendly rice farming practices through the use of organic fertilizers, 2) bringing capital access closer to farmers by paying attention to the ease of the capital application process, as well as the implementation of rational payment mechanisms for farmers, 2) providing market incentives for farmers, 3) optimizing the use of agricultural technology and digital information technology, 4) optimizing the role of agricultural extension workers and strengthening farmer group institutions. Ngawi Regency: 1) policy acceleration through knowledge dissemination in the environmental and health sectors, 2) establishing regulations for the circulation of rice outside the region, in order to create an effective supply chain, increase farmer margins, and protect the selling price of rice, 3) acceleration between technical knowledge workers and access to agricultural capital needs to be improved as a component in achieving maximum harvest results. Madiun Regency: 1) Developing policies to protect and empower farmers, 2) developing policies to protect small-scale rice as a working partner for farmers, 3) establishing a sustainable rice forum that has the function of monitoring and improving sustainable rice farming in Madiun Regency.

By emphasizing the principles of environmental care and concern, improving the farmer's economy, the welfare of farmers and society, supporting technology and sustainable innovation, as well as institutional and policy support, it will be possible to increase the sustainability index for rice cultivation standards in the future.

Acknowledgment

Appreciation and thanks are expressed to all parties who have played a role, contributed, and/or provided support for the preparation of research on the analysis of the sustainability of rice cultivation in rice production centers, namely, to the regional government of the Districts. Boyolali, the regional government of Kab. Klaten, district government. Sragen, District Government. Ngawi, District Government. Madiun, farmers, CSOs, and all parties who play a role, both individually and institutionally. This research was carried out with grant funds from Switch Asia-EU in the low-carbon rice project.

References

1. SUSENAS, Consumption expenditure of population of Indonesia (BPS-Statistic Indonesia, Jakarta, 2024)
2. Z. Arifin, N. Hanani, D. Kustiono, R. Asmara, R.Forecasting the basic conditions of Indonesia's rice economy 2019-2045, Agricultural Socio-Economics Journal, **21**(2) (2021).
3. M. Connor, A. H de Guia, A. B. Pustika, Sudarmaji, M. Kobarsih, J. Hellin, Rice farming in central Java, Indonesia—adoption of sustainable farming practices, impacts and implications. Agronomy. **11**(5), 881 (2021)
4. R. Tirtalistyani, M. Murtiningrum, R.S. Kanwar, Indonesia rice irrigation system: Time for innovation. Sustainability, **14**(19), 12477 (2022)
5. BPS, Complete Enumeration Results of the 2023 Census of Agriculture in Sragen Regency (BPS-Statistics Sragen Regency, Sragen, 2024)

6. BPS, Average Monthly Paddy Prices According to Quality, Quality Components and HPP at Farmer Level (BPS Statistics Indonesia, Jakarta 2024)
7. BPS, Complete Enumeration Results of the 2023 Census of Agriculture in Sragen Regency (BPS-Statistics Boyolali Regency, Boyolali, 2024)
8. A. Pratama, A. Suryantini, A., H. Perwitasari, Sustainability of the different rice cultivation practices in Yogyakarta, Indonesia. Caraka Tani: Journal of Sustainable Agriculture, **39**(2), 321-342 (2024).
9. A.Y. Ismail, M.F. Nainggolan, S.A. Andayani, A.Y. Isyanto, Sustainable Rice Farming in Indonesia. Afr. J. Food Agric. Nutr. Dev. **24**(2), 25409-25425 (2024). https://doi.org/10.18697/ajfand.127.23490
10. Sustainable Rice Platform, Sustainable Rice Platform Standard for Sustainable Rice Cultivation. (2023). https://sustainablerice.org/wp-content/uploads/2022/12/NO-202308-ST-EN-SRP-Standard-for-Rice-Cultivation-V2.2.pdf
11. M. Yusuf, M. Wijaya, R.A Surya, I. Taufik, MDS-RAPS teknik analisis keberlanjutan (Tohar media, Makassar, 2021).
12. B. Santoso, E. D. Manurung, D. R. Siagian, H. F. P. Purba, P. Sembiring, P, Sustainability study of horticultural development in Mandailing Natal District with Rapfish-MDS analysis. Agro Bali: Agricultural Journal, **6**(2), 286-302 (2023).
13. S. S. Devi, G. Wirakusuma, Thriving fields: a study on the sustainable practices of organic rice farming in Sleman Regency. Journal of Agribusiness Management and Development, **5**(2), 14-22 (2024).
14. D. Oktarina, A. M. Kusuma, Analisa Kondisi Jaringan Irigasi (Studi Kasus: Daerah Irigasi Way Kandis Lampung). Jurnal Komposit: Jurnal Ilmu-ilmu Teknik Sipil. **5**(1), 1-5 (2021).
15. R. Nurmalina, Keberlanjutan sistem ketersediaan beras nasional: Pendekatan teknik ordinasi rap-rice dengan metode multidimensional scaling (MDS). Jurnal Agribisnis dan Ekonomi Pertanian. **2**(2) (2008).
16. E.A Rachman, Dasar-dasar kesehatan dan keselamatan kerja (Nasmedia, Klaten 2024)
17. Permatasari, Pengaruh edukasi keselamatan dan kesehatan kerja (K3) terhadap peningkatan pengetahuan petani bawang di Kabupaten Kendal. Jambura Journal of Health Sciences and Research. **5**(4) 1058-1067 (2023)
18. R. Sapbamrer, A. Thammachai, Factors affecting use of personal protective equipment and pesticide safety practices: A systematic review. Environmental research. **185**, 109444 (2020)
19. C. Watson, O. Troynikov, H. Lingard, Design considerations for low-level risk personal protective clothing: a review. Ind. Health. **57** (3), 306–325. (2019) https://doi: 10. 2486/indhealth.2018-0040
20. G. Carracelas, J. Hornbuckle, J. Rosas, A. Roel, Irrigation management strategies to increase water productivity in Oryza T sativa (rice) in Uruguay. Agricultural Water Management, 161–172 (2019)
21. B. Wichaidist, A. Intrman, S. Puttrawutichai, C. Rewtragulpaibul, S. Chuanpongpanich, C. Suksaroj, The effect of irrigation techniques on sustainable water management for rice cultivation system-a review. Applied Environmental Research, **45**(4).
22. Noviani, N., Wahyuni, S., Handayani, L., & Hermanto, B. (2021). The Role Of Farmers Groups In Increasing Sustainable Rice Paddy Farming Business In Lubuk Bayas Village Of Perbaungan Subdistrict. Jurnal Ilmiah Teunuleh, **2**(4), 9-14.
23. Kumar, V., Wankhede, K. G., & Gena, H. C. (2015). Role of cooperatives in improving livelihood of farmers on sustainable basis. American journal of educational research, **3**(10), 1258-1266. DOI:10.12691/education-3-10-8
24. Fyka, S. A., Rianse, U., Yunus, L., & Limi, M. A. (2025). Sustainability Evaluation of Mina Padi Farming in Lebak Swamps Using the MDS Method. Jurnal Ilmiah Membangun Desa dan Pertanian, **10**(1), 34-46.

25. Yuli, S. Astono, M. Fertiaz, Subhan, C. A. O. Sugistria, H. Prayitno, R. I. Khair, A. Brando, B. A. Putri, Occupational Safety and Health Profile Indonesia National 2022 (Ministry of Manpower of the Republic of Indonesia, Jakarta, 2022)
26. R. S. HS, A. Wahyuni, A. Awaluddin, Factors Related to Compliance with PPE use by farmers in Lempang Village. Hasanuddin Journal of Public Health, **3**(1), 56-64 (2022).
27. M. Ishfaq, M. Farooq, U. Zulfiqar, S. Hussain, N. Akbar, A. Nawaz, S. A. Anjum, Alternate wetting and drying: A water-saving and eco-friendly rice production system. Agricultural Water Management, **241**, 106363 (2020).
28. F. J. Proctor, V. Lucchesi. Small-scale farming and youth in an era of rapid rural change, (International Institute for Environment and Development (IIED)/HIVOS, London, 2012).
29. S. H. Susilowati, Incentive Policy for Young Farmers: Lesson Learned from Various Countries and the Implications for Indonesian Policy. Forum Penelitian Agro Ekonomi, **34**(2), 103-123 (2016)