Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

CASE STUDY

Sustainability index analysis for environmentally low-input integrated farming

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ARTICLE INFO

Article History:
Received 29 June 2023
Revised 03 September 2023
Accepted 11 October 2023

Keywords:
Low-input integrated farming
Multi-dimensional scaling (MDS)
Sustainability

DOI: 10.22035/gjesm.2024.02.08

ABSTRACT

BACKGROUND AND OBJECTIVES: Integrated farming is an efficient and environmentally friendly agricultural activity that uses low-input resources, including abundant local materials, such as waste. According to previous studies, this program has been adopted by the Indonesian government to facilitate the achievement of sustainable agriculture. Therefore, this study aimed to evaluate the level of sustainability of low-input integrated agricultural farming by determining and analyzing the sustainability index.
METHODS: Experts and business operators engaged in the integrated production of organic fertilizer, corn, and laying hen farming conducted scientific assessments to gather primary and secondary data. This was carried out through Focus Group Discussions and the completion of a questionnaire containing 34 attributes linked to environmental, economical, social, technological, and institutional aspects. The data obtained were then analyzed using a multidimensional scale technique. Monte Carlo analysis and alternating least-squares algorithm were used to examine sustainability status and significant characteristics.
FINDINGS: The degree of agricultural integration's sustainability from organic fertilizer, corn, and layer hen farming was 86.10 percent. The results showed that techniques in several stages of the organic fertilizer production process, corn cultivation with the application of organic fertilizer, and laying hen farming with local feed, harvesting, and marketing, contributed to sustainable development by considering the strength aspects from each dimension. Based on the analysis results, the social dimension had a sustainable index score of 93.79 percent, followed by economic (90.57 percent), institutional (88.39 percent), environmental (83.45 percent), and technology (74.29 percent). Based on the findings, the factors that should be considered included 1) Efficiency in the utilization of water during egg, 2) fertilizer production and effectiveness of using fuel and electricity during the production and marketing, 3) an Industry manager level of education, 4) the ease by which raw materials can be obtained for the integration industry, 5) potential for increasing the low-input integrated agricultural farming, 6) the availability of integration industry facilities, infrastructure and level of expertise needed by managers in the people's integration sector, 7) Financial institutions' existence.
CONCLUSION: Multidimensional mapping showed that the low-input integrated agricultural farming in the dry land of Pangkalan Lada District was running sustainably, with an average sustainability index of 86.10 percent. These results indicated that the integration of organic fertilizer, corn, and layer hen farming in the area had successfully optimized the available resources, created a sustainable farming model, and had the potential for adoption in various locations and future periods. The five evaluated dimensions showed good sustainability levels, with sustainability indices ranging from 74.29 percent (sustainable with a fair level) to 93.79 percent (very sustainable). Therefore, sustainability improvements in these farming activities must focus on technological aspects, with an emphasis on technological attributes that offered valuable insights for the government in formulating policies and programs.

NUMBER OF REFERENCES
87

NUMBER OF FIGURES
7

NUMBER OF TABLES
4

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Note: Discussion period for this manuscript open until July 1, 2024 on GJESM website at the "Show Article".

INTRODUCTION

The Indonesia National Medium-Term Development Plan (RPJMN) for 2020-2024 represents the fourth stage and continuation of the Indonesia National Long-Term Development Plan (RPJPN) for 2005-2025. In the fourth RPJMN (2020-2024), the development of the agricultural sector is expected to enhance food security and competitiveness, leading to the actualization of an advanced, self-reliant, and modern agriculture sector within the country (Ministry of Agriculture, 2021). Several studies have shown that sustainable food security is related to production and closely linked to the engagement and empowerment of farmers who play a frontline role in creating food supplies. Food security is also associated with the management of natural resources. Furthermore, unsustainable exploitation of resources can lead to environmental degradation, soil damage, and negative impacts on agricultural productivity, leading to a decline in the quality and quantity of food production. These challenges can be attributed to the lack of education and training for agricultural practitioners, specifically farmers. According to previous studies, rural farmers do not have adequate access to the latest information and technology for the improvement of production. The lack of access to information, educational opportunities, and training impedes the implementation of Precision Agriculture concepts, such as the use of sustainable fertilizers and pesticides, as well as innovative practices in land management. Precision Agriculture approaches can increase productivity while reducing negative environmental impacts. The low-input integration of agricultural farming or synergy between agriculture and livestock has become a part of the government's programs aimed at providing a solution for sustainable development. Integrated farming systems comprise multiple enterprises or efforts that interact in space and/or time, leading to a synergistic resource transfer among enterprises (Archer *et al.,* 2019). The concept is also described as an agricultural system that uses the three interacting dimensions, namely organization, space, and time (Bell and Moore, 2012). In several developing countries, an integrated farming system is a common practice due to the limitation of farmland acreage, and access to manufactured fertilizers and agrochemicals (Archer *et al*., 2019). At present, the implementation of modern agriculture to enhance production requires intensive inputs. Crop rotation systems and polyculture plants can reduce the intensive input while increasing crop yield, enhancing nutrient cycling, reducing plant disease, and improving soil quality (Hendrikson, 2008). Therefore, the integrated farming system has a potential benefit to environmental aspects and sustainability. For example, its implementation between livestock and cropping systems often enhances nutrient cycling efficiency, adds value to grain crops, and provides forages and crop residue. The integration can spread economic and production risk over several different enterprises and take advantage of a variety of agricultural markets. This is evident in various initiatives, such as the integration of oil palm cultivation with cattle farming from 2007 until now, the integration of cattle with cocoa crops from 2007 to 2010, the combination of cattle with sugarcane starting in 2009 until 2012, and the integration of cattle with coconut crops since 2013. Integrated farming systems, as described by Paramesh *et al*. (2020), represent an agricultural approach that combines activities in food crops, horticulture, livestock, fisheries, forestry, and other agricultural elements within a region simultaneously. This system is often implemented due to the increasing management inputs, presence of more enterprises, market challenges, and environmental concerns of consumers (Hendrickson *et al*., 2008). The farmer needs to manage the combination of agricultural commodities, different enterprises, and other complexities to achieve sustainable production. The principle of the sustainability of an integrated farming system comprises three dimensions, including economic, environmental, and social-community. Integrated agricultural systems can reduce the environmental impact of agriculture and increase adaptability, which is the greatest contributor to long-term sustainability. The correlation between the state-of-the-art analysis and knowledge gaps have been drawn in Fig. 1.

Compared to traditional farming models, this approach provides greater ecological and social advantages, including increased gains, higher input-output ratios, improved soil performance, and mitigation of the impacts of global warming (Yang *et al.,* 2022). The concept of sustainable agriculture has been subjected to development, initially focusing on ecological aspects, then expanding to include economic dimensions, and encompassing greater

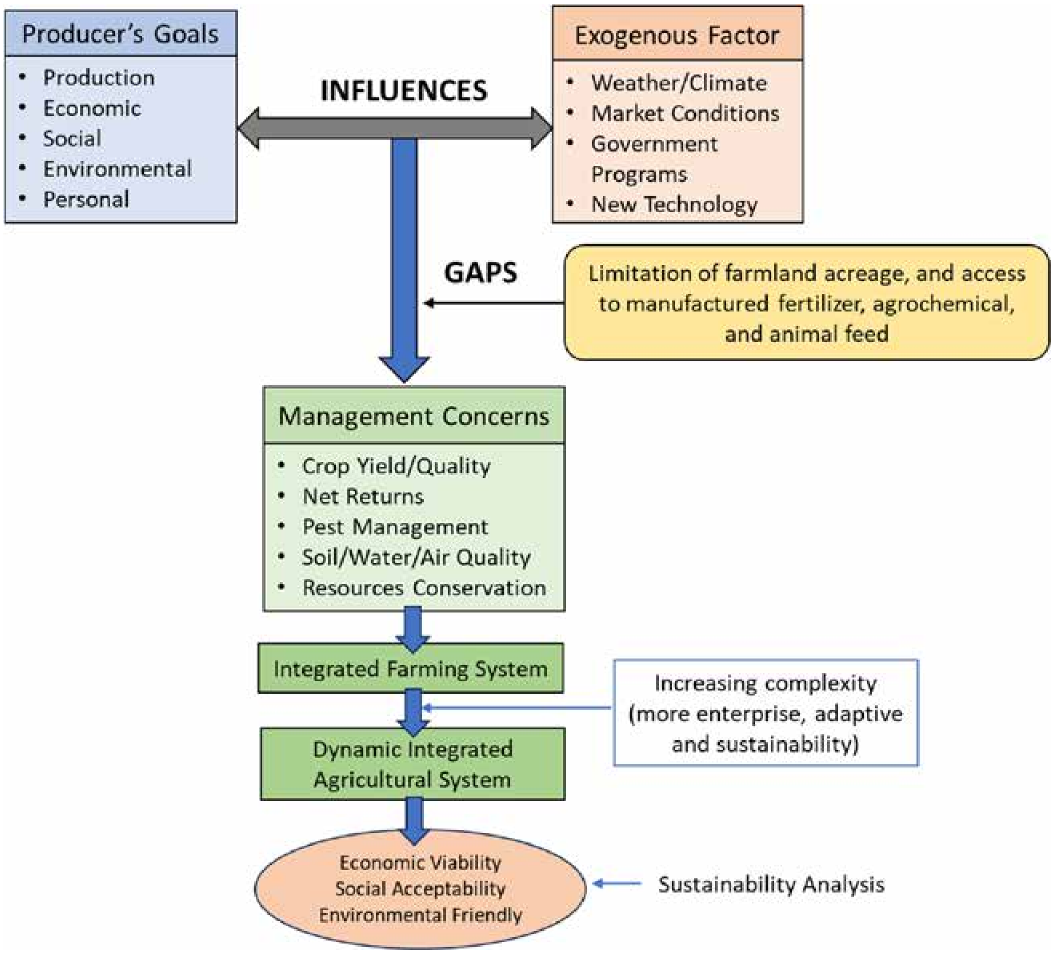

Fig. 1: The correlation between the state-of-the-art analysis and knowledge gaps (Tanaka *et al*., 2002)

social dimensions. Having less of an adverse influence on the environment and people's health, maximizing the utilization of local ecosystem resources, and preserving biodiversity are the core principles of sustainable agriculture (Asadi *et al.,* 2013). According to Suradisastra (2017), sustainable agricultural development must encompass various aspects, including technical, technological, socio-cultural, economic, and conservation (environmental). The implementation of the concept is the utilization of by-products or waste from each production subsystem as a source of livestock feed and fertilizer, thereby creating the concept of Low External Input Sustainable Agriculture (LEISA). The use of waste, specifically from the oil palm mill, such as solid oil palm, palm kernel meal, fiber, and boiler ash for fertilizer and animal feed has been previously reported (Grinnell *et al.,* 2022). The technology has been widely adopted by the community, and reported by several studies (Bremer *et al.,* 2020). Due to environmental issues with the composting of agricultural wastes, experts examine and develop a solid waste management plan employing alternative techniques. The solid waste industry has approved several techniques or procedures used in the previous 20 years to treat agricultural waste (Aziz *et al*., 2022). Different types of organic materials, including cellulose, hemicellulose, lignin, and starch, can be found in agricultural waste (Suhartini *et al.,* 2022). In high-income countries, the government typically covers the costs of trash processing (Rindhe *et al*. (2019)). However, this is not the case in low-income nations where more resources are needed to establish waste management infrastructure. Composting of agricultural waste can be evaluated for sustainability by computing the sustainability index using Multi-dimensional scaling (MDS). A multivariate statistical approach called multidimensional scaling is used as a variable to position items according to their similarities and differences. People's preferences or opinions are often transformed by MDS into multidimensional distances that can be scientifically described. MDS refers to a variety of statistical methods that compress preference data by visualizing the underlying relationships between groups (Wan *et al*., 2021). It has also been reported to have the ability to interpret and refine respondents' preferences or opinions concerning the agricultural integration production sustainability index theme. This study used five dimensions (environmental, social, economic, technological, and institutional) to provide suggestions and help decision-makers in sustainable development. It was also hypothesized that implementing integrated agricultural production can minimize pollution while also improving soil conditions. However, it was important to identify the most significant attribute for each of the environmental, social, economic, and technological dimensions. The MDS practical approach offers information to help decision-makers in the agricultural integration production with waste management. The study objectives are 1) measuring the overall sustainability index value, 2) calculating the sustainability index for each dimension: environmental, social, economic, technological, and institutional, and 3) examining important influences on integrated agricultural production systems. This study evaluates the feasibility of an integrated production supply system and was conducted in seven groups at the National Research and Innovation Agency and the Ministry of Agriculture, Republic of Indonesia, from 2022 to 2023.

MATERIALS AND METHODS

Study procedure

Experts and business operators engaged in the integrated production of organic fertilizer, corn, and laying hen farming conducted scientific assessments to gather primary and secondary data. This was carried out through Focus Group Discussions and the completion of a questionnaire containing 34 attributes linked to environmental, economic, social, technological, and institutional aspects. The data were analyzed using a multidimensional scale technique. Monte Carlo analysis and alternating least-squares algorithm were utilized to examine sustainability status and significant characteristics. Focus group discussions (FGD) were carried out to analyze the survey data, and six experts, including corn farmers, poultry farmers, organic fertilizer experts, and business actors, were surveyed. The qualifications of experts in filling out the questionnaire were those who had at least five years of experience in integrated production management. Furthermore, it was intended to evaluate the current business player environments and resource support for integration production for designing dimensions and attributes. The total number of attributes used in this study was 34 with five dimensions, namely environmental, social, economic, technological, and institutional. A questionnaire with response options using a Likert scale described these dimensions and attributes. The Expert respondents responded to the questionnaire questions by scoring 0 for poor, 1 for average, and 2 for good. Organic fertilizer in this activity was a mixture of ingredients from palm oil mill by-products consisting of fiber, solid palm oil, empty fruit bunches, and boiler ash, which were enriched by microbes. The results of the laboratorium analysis are presented in Table 1.

Data analysis

The MDS method was used in the data analysis through the Rap-integration technique (Rapid Appraisal for Integration Production). This technique was an adoption and development of the Rapfish (Rapid Appraisal for Fish) method to measure the sustainability of organic fertilizer production. The stages for determining a sustainability index are presented as follows (Lloyd *et al.,* 2022).

1) Assess each attribute of the sustainability dimension. This study had six dimensions with a total of thirty-four attributes.

2) Give a score to each attribute. A matrix X of size (n x p) was formed with attribute score elements, where n was the number of regions and their reference points, and p was the number of attributes, using Eq. 1 (Borg *et al.,* 2018).

Table 1. The result of laboratory examination of organic fertilizer based on palm oil mill by-product

No.	Types of Testing	Test methods	Test results
1	Potential of hydrogen (pH)	pH meter	11.12
2	Nitrogen (percent) (%)	Kjeldahl	0.40
3	Phosphorus (P) (%)	Spectrophotometry	1.42
4	Potassium (K) (%)	Atomic absorption spectrometry (AAS)	0.75
5	Sodium (Na) (%)	AAS	2.04
6	Calcium (Ca) (%)	AAS	4.80
7	Magnesium (Mg) (%)	AAS	1.06
8	Organic carbon (OC) (%)	Spectrophotometry	1.81
9	Iron (Fe) (ppm)	AAS	3,344.97
10	Copper (Cu) (ppm)	AAS	96.56
11	Manganese (Mn) (ppm)	AAS	318.76
12	Zinc (Zn) (ppm)	AAS	88.46
13	Lead (Pb) (ppm)	AAS	27.05
14	Sulphurous (S) (5%)	Spectrophotometry	0.30

$$X_{ik}sd = \frac{X_{ik} - X_k}{s_k} \quad (1)$$

where:

$X_{ik}sd$ = the i^{th} k^{th} attribute regional standard score (including reference points), where i = 1, 2, …, n and k = 1, 2, …, p

X_{ik} = the i^{th} k^{th} attribute standard score (including reference points), where i = 1, 2, …, n and k = 1, 2, …, p

= the k^{th} attribute mean score, where k = 1, 2,…, p

S_k = the k^{th} attribute standard deviation score, where k = 1, 2, …, p

Eq. 2 (Borg *et al.,* 2018) was used to calculate the shortest distance according to the Euclidean distance. This distance was then converted into a two-dimensional Euclidean space, (d12) using the regression formula stated in Eq. 3 (Borg *et al.,* 2018). The ALSCAL algorithm was employed in the regression process to perform iterations until the intercept value in the equation reached zero (a=0). Therefore, Eq. 3 was transformed into Eq. 4 (Borg *et al.,* 2018). When the stress value (s) <0.25 was reached, the repetition process was stopped, and the S value was attained using Eq. 5 (Borg *et al.*, 2018).

$$d = \sqrt{\left(|x_1 - x_2|^2 + |y_1 - y_2|^2 + |z_1 - x_2|^2 + \ldots\right)} \quad (2)$$

$$d_{ij} = \alpha + \beta\delta\beta_{ij} + \varepsilon \quad (3)$$

$$d_{12} = bD_{12} + e; \quad (4)$$

$$s = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i\sum_j\left(d_{ijk}^2 - o_{ijk}^2\right)^2}{\sum_i\sum_j o_{ijk}^4}\right]} \quad (5)$$

3) Assess and determine sustainability index and status. The sustainability status category for the sustainability of integrated production could be classified into four categories based on the sustainability index. These categories were highly (75.01-100.00), moderately (50.01-75.00), less (25.01-50.00), and not sustainable (0.00-25.00).

4) Conduct a sensitivity (leverage) analysis to measure the critical attributes that strongly influenced the sustainability of the integration production system. This analysis was based on the priority order of changes in the root mean square (RMS) ordination on the x-axis. When the RMS had a substantial value, it indicated that the function of this feature in determining sustainability was becoming more prominent (more sensitive).

5) Monte Carlo analysis was utilized in the Rap-

Integration technique to calculate the random error rate in the model produced from the MDS analysis for all dimensions at the 95% confidence level. The lesser the value difference between the MDS and Monte Carlo analysis findings, the better the Rap-Integration method's Monte Carlo model. In MDS, the values of S and the coefficient of determination (R^2) reflected the degree of fit. A low S value implied a favorable match, while a high S value indicated an unfavorable match. A solid Rap-fertilizer model had a S value smaller than 0.25. An R^2 number near one indicated that the qualities used to assess a dimension were reasonably accurate (Pitcher and Preikshot, 2001; Samimi *et al.*, 2023).

To evaluate sustainability, the multidimensional scaling (MDS) method had become widely used. Furthermore, it had been extensively utilized to evaluate the viability of producing various agricultural commodities. Table 2 shows previous analyses of agricultural product sustainability using the MDS approach.

Ecological/environmental, economic, social, technological, and institutional factors were the most frequently used in previous studies on sustainability.

Table 2: Previous study utilizing MDS analysis

No.	Title/topic study	Dimensions	Sources
1	MDS preference plot for agricultural data visualization analytics	social, environmental, economic	Zhang and Ding, 2023
2	Visual analytics of agricultural data by MDS preference plot	environmental, economic, social	Papilo *et al*., 2023
3	Policy-related Biodiesel Sustainability in Indonesia	economic, ecological, social	Dharmawan *et al*., 2020
4	Sustainability of plants and supporting facilities	ecological, economic, social	Giuntoli *et al*., 2022
5	Sustainability agricultural development	social, ecological, economic, institutional	Suardi *et al*., 2022
6	Sustainability of microalgal biomass production	ecological, social, economic, technological	Santoso *et al*., 2023a
7	Sustainability garlic production	environmental, technological, economic, social, and institutional dimensions	Paczka *et al*., 2021
8	The sustainable cultivation of cocoa	environmental, social, economic, institutional dimensions, and technological	Fairuzia *et al*., 2020
9	Sustainability of organic fertilizer production	environmental, social, economic, institutional dimensions, and technological	Santoso *et al*., 2023b
10	Sustainability corn production	environmental, technological, social, economic, and institutional dimensions	Ariningsih *et al*., 2021
11	Sustainability assessment of chili farming	environmental, economic, social, technological, and institutional dimensions	Mailena *et al*., 2021
12	Sustainable production of beef cattle	dimensions of the environment, society, economy, technology, and institutions	Kapa *et al*., 2019
13	Sustainability of dairy cattle production	dimensions of environmental, social, economic, technological, and institutional	Lovarelli *et al*., 2020
14	Sustainability buffalo production	environmental, economic, technological, and social dimensions	Rohaeni *et al*., 2023
15	Sustainability shrimp production	dimensions of environmental, social, economic, technological, and institutional	Sivaraman *et al*., 2019
16	Sustainability coffee production	environmental, social, economic, and technical aspects	Yusuf *et al*., 2022
17	Sustainability rice production	institutional, environmental, social, economic, and technical aspects	Rachman *et al*., 2022
18	Sustainability of red chili production	technical, social, economic, and environmental aspects	Nuraini and Mutolib, 2023
19	Sustainability of black soldier fly production	social, economic, environmental, and technical aspects	Santoso *et al*., 2023c

Other studies carried out analysis using ethical, commercial, and political factors. Those studies had varied ideas on the number and types of metrics to be used.

RESULTS AND DISCUSSION

Dimension and attribute

The MDS approach was used to determine the amount of sustainability in integration manufacturing. The variables and qualities affecting sustainability were determined by extensively examining their effects on Integration production (Lloyd *et al.,* 2022). The study included 34 attributes across five dimensions, namely environmental, economical, social, technological, and institutional. The data used to calculate the MDS were obtained from a questionnaire, and Table 3 had a complete breakdown of the dimensions and attributes.

To get expert perspectives on the scientific viability of composting processes for manufacturing

Table 3: Dimensions and attributes of the low-input integrated agricultural farming sustainability

No.	Dimension	Attributes	
1.	Environmental	1. Effective use of biodegradable materials for the production of eggs and fertilizer 2. Effectiveness of using chemicals in the production of eggs and fertilizer 3. Effectiveness in the use of electrical energy and fuel during the production and marketing 4. Effectiveness in the use of water during egg and fertilizer production	5. Possibility of air pollution (odor generated) 6. Possibility of water pollution 7. Utilization of natural resources (land, biota, and plants) in the production of eggs and fertilizer 8. Potential for illness to spread because of the integration industry 9. Possibility that the integration industry will harm biodiversity
2.	Social	10. Industry manager or entrepreneur's level of education 11. Family members working in the integration industry 12. Level of business motivation 13. Possibility of public unrest due to the integration industry 14. Possibility of losing other jobs because of the integration industry	15. Managerial or employee-level expertise in the conservation and restoration of the environment 16. Risk of workplace accidents 17. Possibility of creating jobs for the community
3.	Economical	18. Productivity level of the integration industry 19. Management level of the integration industry 20. Possibility of increase in business scale/business success rate e	21. Enhancing the welfare of managers and employees 22. Efficiency in using raw materials and the simplicity with which raw materials can be obtained for the integration industry 23. Market penetration of the integration industry
4.	Technological	24. Part of the community's ability to quickly adopt the integration industrial system 25. Partially required specialization, experience, and/or skill set for managers in the people's integration industry	26. Availability of integration industry facilities and infrastructure 27. Possibility of increasing integration production 28. Sensitivity of the technical/method to the level and scope of the integration industry
5.	Institutional	29. The actuality of the manager of this integration activity 30. The actuality of integration business rules from the government 31. Availability of assistance from the authorities/government	32. The actuality of a group of fellow entrepreneurs/managers 33. The actuality of financial institutions that help 34. The actuality of marketing agencies

organic fertilizer, the characteristics within each dimension were compiled into a questionnaire and distributed to the appropriate professionals. The Rapfish program and the MDS technique were used to examine the results of these professional reviews. The sustainability ratings for each dimension are shown in Table 4.

Environmental carrying capacity, production input accessibility, production techniques, processing, egg, corn, and fertilizer marketing, and the responsibilities of relevant organizations were factors with a long-term impact on integrated production. Furthermore, integration production systems could replace conventional animal feed production as an economically and environmentally sound alternative by considering these aspects and implementing sustainable methods (Rehman *et al.*, 2020). The results of the MDS study on the creation of environmentally friendly integrated production were given in Fig. 2 with a stress value of 0.15 (stress 50%). This demonstrated the reliability and precision of the five dimensions calculated by the Monte Carlo test. The integration production system had a sustainability value of 86.10. The social dimension had the highest level of sustainability, while the technological dimensions had a fair sustainability category, as illustrated in Table 4.

Table 4 showed the results of running the validity of the MDS analysis findings at the 95% confidence level, as determined by the goodness of fit value, namely the stress value and R^2. The stress value quantified the difference between the model and the real data. The R^2 value was a measure of precision that assessed the model's capacity to explain fluctuations in the dependent variable (Leven *et al*., 2023; Samimi and Mansouri, 2024). The stress value (0.136-0.144) in Table 4 was less than 0.25, showing that the model was close or similar to the actual scenario due to the low mismatch value. Meanwhile, the coefficient of determination (R^2) ranged between 0.936-0.949. The higher the value was closer to 1, the higher the quality of the analysis performed. It indicated that additional attributes were not required in the case studied, and the aspects analyzed were accurately close to the actual conditions (Saputro *et al.,* 2023). According to Suardi *et al.,* 2022, all attributes used in the analysis of the sustainability of the production process through the integration of organic fertilizers corn

Table 4: The sustainability index for all dimensions

Dimension	Index (%)	Stress	R^2(SQR)	Status
Environmental	83.45	0.136	0.947	good sustainable
Social	93.79	0.137	0.949	good sustainable
Economical	90.57	0.136	0.946	good sustainable
Technological	74.29	0.144	0.936	fairly sustainable
Institutional	88.39	0.143	0.941	good sustainable
Average	86.10			good sustainable

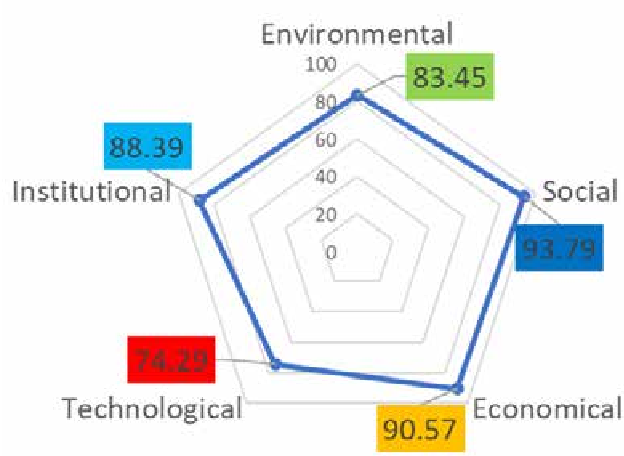

Fig. 2: The level of sustainability achieved in integration production

cultivation, and layer hen farming on dry land in the Pangkalan Lada Subdistrict were good at explaining the five dimensions analyzed. The foregoing results could also be interpreted as indicating that the model produced was good and accurately described the topic under consideration (Rachman *et al*., 2022).

Environmental dimension

According to Asadi *et al*. (2013), the environmental dimension had a substantial impact on sustainable agriculture. This activity's sustainability assessment for the environmental dimension included nine attributes, which were listed in Table 3. The results showed that the environmental component had an index value of 83.45%, a stress value of 0.136, and a structured query reporter (SQR) value of 0.947, indicating the achievement of (Table 4). This was a commendable index achievement that merited future enhancement. It showed that the production process in Pangkalan Lada Subdistrict had considered environmental preservation and ecosystem balance by including organic fertilizers, corn cultivation, and layer hen farming on dry land. This was understandable given the implementer's prior experience with implementing Roundtable on Sustainable Palm Oil (RSPO) and Indonesian Sustainable Palm Oil (ISPO) in managing oil palm plantations (Widiati *et al.,* 2020). The dimension was positively rated in the context of sustainability since ISPO and RSPO were used in their management (Afrino *et al.,* 2023). Based on the attribute leverage analysis results for the environmental dimension show that two attributes, namely Efficiency in the use of water during egg and fertilizer production and Efficiency in the use of electrical energy and fuel during production and marketing had RMS values of 7.88 and 7.25 respectively (Fig. 3). These findings had a substantial impact on the sustainability of this

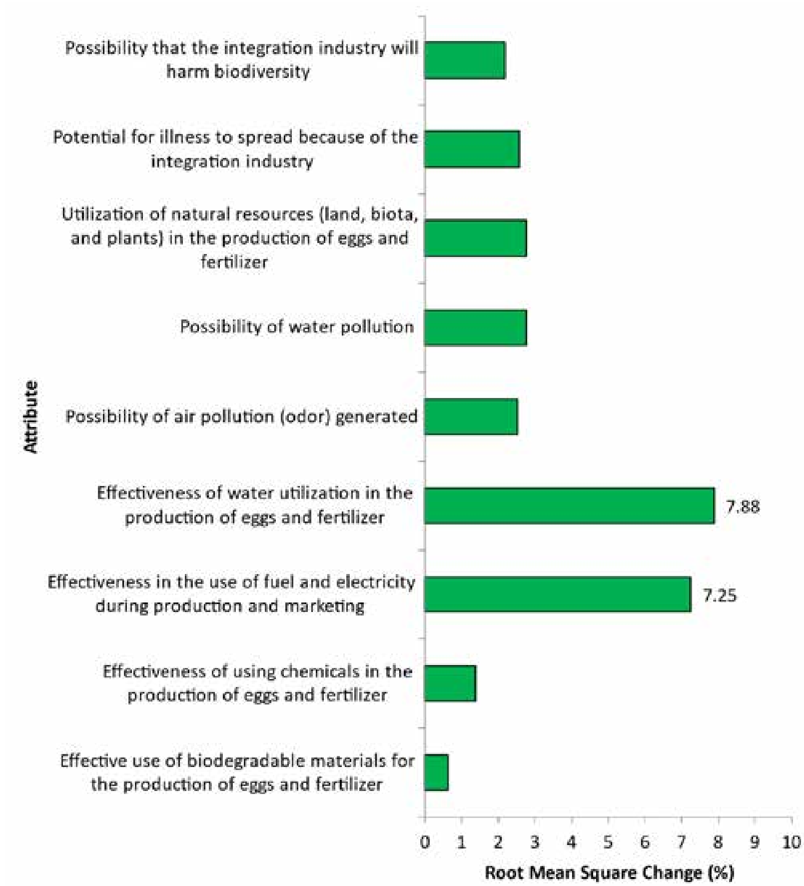

Fig. 3: Leverage of environmental attributes

activity in the context of the environment. To reach a high level of sustainability, it was necessary to improve the management of these traits. The values of the other attributes had no substantial impact, but attention must still be taken to ensure the preservation of the environmental dimension within the context of sustainability. In the environmental dimension of agricultural activities, efficiency had become a sensitive issue (Asadi *et al*., 2013). Regarding the efficient use of electrical energy and fuel, the potential of palm oil mill waste on site, aside from animal feed (Wadchasit *et al*., 2021) and fertilizer should be considered for its utilization as an electricity resource (Mahidin et al., 2020) and a fuel, such as biogas (Tiong *et al*., 2021). Several studies had shown that community waste could be transformed into electricity (Abdoli *et al*., 2012). The use of liquid waste for other purposes in the agricultural industry was an important topic in environmental sustainability. It was important to recycle and reuse wastewater to meet future human demand and reduce water scarcity, as well as ensure compliance with wastewater discharge standards for environmental sustainability while minimizing groundwater and soil contamination.

Social dimension

The sustainability assessment for the social dimension using eight attributes is presented in Table 3. The results indicated that the social aspect had an index value of 93.79%, a SQR score of 0.949 with a stress value of 0.137, indicating the fulfillment of the criteria (Table 4). Compared to the environmental dimension status, it had a good index, which was worthy of being maintained and improved. The indicator showed that the production process in this activity carried out in the dry lands of the Pangkalan Lada sub-district, had a good social involvement in the sustainability of this activity. Compared to other dimensions, the social element had the highest sustainability index among the five aspects. A similar finding was reported by Surahman *et al*. (2018),

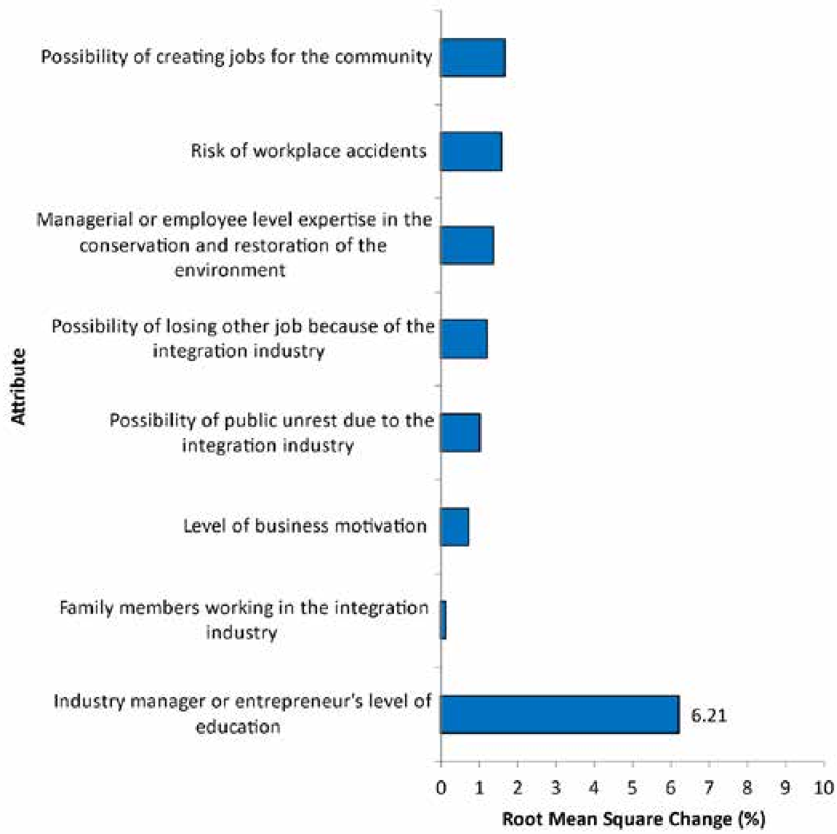

Fig. 4: Leverage of social attributes

where the social dimension had the highest value for peat land farming. According to Surahman *et al*. (2018), this activity was thought to be due to the establishment of the use of land for agriculture. The results of social sustainability dimensions in Fig. 4 indicated that out of the eight attributes reviewed, one sensitive attribute influencing the sustainability of this activity was the level of education of industry managers or entrepreneurs. Education level in this context was not limited to formal education but also emphasized the accumulation of experience and acquired information. For example, the intensity of counseling, training, and experience could have a significant impact on the success of implementing this activity. These findings were consistent with Asadi *et al.* (2013) who also obtained similar results, In terms of social capital, sustainable agriculture was frequently related to farmer engagement, contentment, technical knowledge, farmer competencies, and social capital. The analysis conducted by Osak and Hartono (2016) suggested that in the social dimension of agricultural integration systems in the livestock and horticulture sector, related to attitudes, responses, and perceptions, improvement was needed through counseling, training, and field demonstrations (demonstration plots) to enhance its social sustainability. In line with the report by Mailena *et al*. (2021), the intensity of counseling, training, and formal education for farmers had a sensitive impact on the sustainability of chili farming. Leven *et al*. (2023) also reported that in the social dimension, attributes, such as the frequency of counseling and training were the most important factors determining the sustainability of milkfish farming activities in Gresik Regency. Training could provide experience and bring out creativity (Janker and Mann, 2020).

Five dimensions (social, environmental, economic, technological, and institutional) with 34 attributes in the integration of organic fertilizers, corn cultivation, and laying hen farming, influenced each other on the sustainability of this integrated farming (Bathaei and Štreimikiene (2023). The integration of the 5 dimensions led to long-term oriented agricultural production, which was economically feasible and did not damage the environment through good management and governance (Sadiku *et al.,* 2021). Furthermore, it was described in each attribute and in each dimension within the integration of organic fertilizers, corn cultivation, and laying hen farming.

Economical dimension

The level sustainability assessment for the economic sector, as presented in Table 3, utilized six attributes. The findings showed that the economic dimension had an index value of 90.57% , a stress value of 0.136, and an SQR value of 0.946, and they met the sustainability criteria (Table 4). This index held a favorable status and was worthy of preservation and further enhancement. Based on these findings, the production process through the integration of organic fertilizers, corn, and layer hen farming in the dry lands of Pangkalan Lada sub-district had sustainable economic value. The presence of agribusiness in the integration system in the study area, as mentioned by Sulistyono *et al.* (2019), was highly beneficial from an economic perspective. These results were inconsistent with Li *et al.* (2020) in the context of monoculture layer chicken farming, where the economic dimension was not sustainable. The note of the leverage attribute analysis for the economical dimension indicates that one attribute, namely the level of ease of getting raw materials for the integration industry (Fig. 5), had a highly significant influence on the sustainability of this activity. In line with Fu *et al.* (2021) and Lin *et al.* (2022), material production was the highest leverage attribute. Efforts to obtain raw materials were crucial to achieve a high level of sustainability. The raw materials referred to in this activity were those used in the production of organic fertilizers and layer feed and were obtained from the palm oil mill in terms of their by-product. The by-product used to make organic fertilizer was fiber, namely 26% from fresh fruit bunches, which were processed into CPO, solid palm oil (3%), empty fruit bunches (16%), and boiler ash. Meanwhile, the by-product used to feed laying hens was palm kernel meal, and it was produced at 4%. These feed ingredients were formulated into alternative feed for laying hens that were tailored to the chicken's nutritional needs, leading to a cost-effective alternative feed. Supporting the local government in obtaining these materials was essential because an official letter of endorsement from the Local Government, which could be provided by the relevant department, was required to access them. According to Bathaei and Štreimikiene (2023), the government could also assist companies in reducing

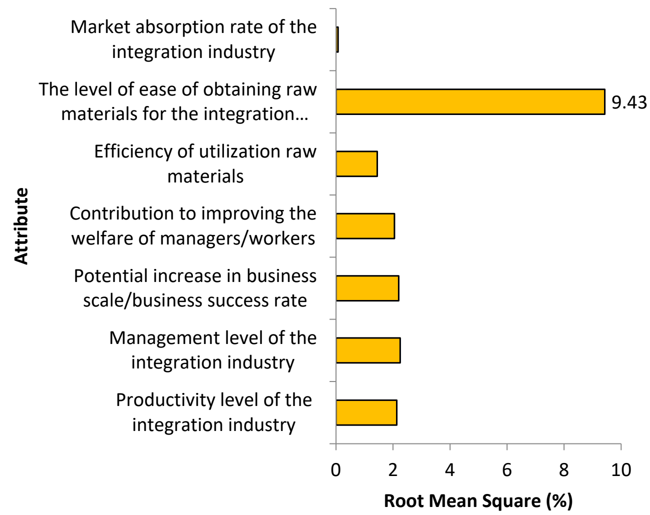

Fig. 5: Leverage of economical attributes

the prices of raw materials and facilitating farmers in purchasing recycled products (by-products). In relation to livestock farming activities, feed played a crucial role as it accounted for 60-70% of production costs (Wongnaa *et al*., 2023). This was evident from the analysis results that raw materials were a primary factor in the economic dimension. Similar findings had been reported by Sulistyono *et al*. (2019) concerning the availability of animal feed, and by Jasmawadi *et al*. (2022) regarding the availability of production raw materials as key drivers in sustainable economic dimensions. Although other attributes did not have significant impacts, attention was still necessary to maintain the economic dimension within the context of sustainability.

Technology dimension

The sustainability assessment for the technology dimension, using five leverage points (Table 3) indicated that it exhibited a fairly good level of sustainability, with an index value of 74.29%. The index value for the technology dimension was lower compared to the index of others. Therefore, serious attention was needed to enhance its sustainability. The stress and SQR both had good values, namely 0.144 and 0.936, respectively (Table 4). Developing an integrated agricultural system required the application of appropriate technology (Paramesh *et al*. (2020). During the use of agro-industry waste, such as palm oil mill waste, there was a need to implement biotechnology to ensure further usage, including fermentation with microbes (Sivakumar *et al*., 2022). The implementation of technology was crucial as it had a positive correlation with the food security of household farmers (Mutenje *et al*., 2016) and farmers' income (Lin and Wu, 2021). Furthermore, it promoted the sustainable and resilient growth of food productivity (Hailu, 2023). The results of the attribute leverage analysis for the technology dimension indicated that there were three attributes with significant influence on the sustainability of this activity, namely; 1) the potential for increasing integration production, 2) the availability of integration industry facilities, and 3) the level of specialization required for managers of the people's integration industry (Fig. 6). Therefore, the technological aspect must receive special attention in efforts to enhance the sustainability of this activities from a technological perspective. Farmers could not typically change the conditions of their farming operations without guidance and support from individuals who possessed expertise in this field and they must be supported by emerging technologies. This task was to be undertaken by agricultural extension workers. In the technology adoption process, the pattern of extension workers included serving as facilitators, motivators (Wedajo *et al*., 2019), consultants, and technical assistants (Indraningsih *et al*., 2023). One of the factors influencing the rapid adoption of agricultural

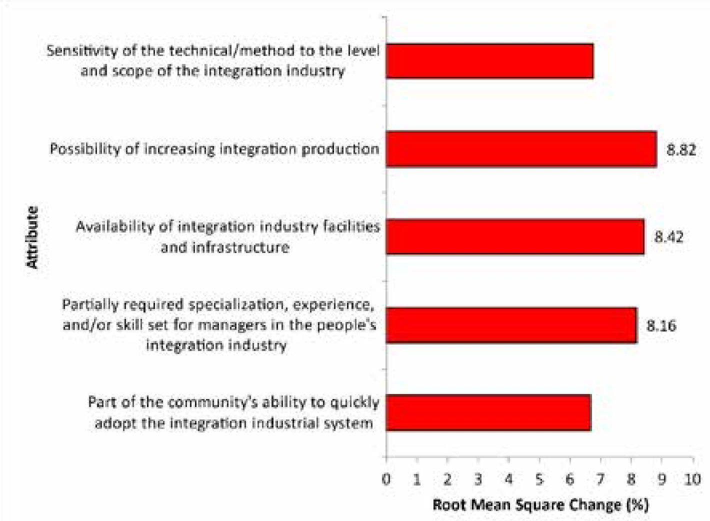

Fig. 6: Leverage of technology attributes

technology innovations by users or farmers was the choice of the type of extension media. Spectrum Dissemination Multi-Channel Spectrum represented an innovation (IAARD, 2011) aimed at expediting and broadening the optimal dissemination reached through various media simultaneously and in a coordinated manner. Furthermore, its effectiveness had been proven in driving the diffusion of technology innovations to users (Bounadi *et al.,* 2022).

Institutional dimension

The institutional dimension was also sustainable, as the sustainability index reached 88.39% with a stress value of 0.143 and an SQR value of 0.936 (Table 4). Institutions in the agricultural sector played an essential role in making the hopes, desires, and needs of farmers come to fruition (Musafiri et al., 2022). These rural farmer organizations were instrumental in advancing the socio-economic advancement of farmers, as they provided access to vital agricultural information, facilitating their access to capital, infrastructure, and markets, as well as promoting the adoption of innovative agricultural practices. The presence of farmer institutions helped to facilitate the government and other stakeholders in their efforts (Šūmane, 2018). The institutional dimension was sustainable, indicating that the institutions were independent. In this situation according to Provotorina *et al.* (2020), institutions functioned as production units and providers of production facilities. This condition was appropriate in the field due to the formation of farmer groups and Village Cooperative Units: Koperasi Unit Desa (KUD), where business units of KUD included those dedicated to agricultural production, savings and loans, and the provision of agricultural production facilities. Therefore, agricultural activities, particularly capital, were not a problem. Based on Fig. 7, the presence of financial institutions providing support was among the six leverage attributes in the institutional dimension that influenced the sustainability of this activity. The sensitivity of this attribute was highly significant compared to other attributes, indicating that financial institutional support had a substantial impact on the sustainability of the production process in the integration of organic fertilizer, corn, and layer hen farming. The key starting point related to finances was also reported by Khaerunnisa *et al.* (2023) and Ningsih *et al.* (2021).

It was suggested that the Indonesian government implement the following actions: 1) Rules and rewards: The government could promote regulations that assisted effective trash management, possibly providing rewards for eco-friendly actions, such as composting and waste conversion; (2) Financial Boost: Offering financial assistance, subsidies, or grants to promote the production of organic fertilizer by farmers, cooperatives, or companies; (3) Building capacity: Government-led training programs to inform participants on the benefits of composting,

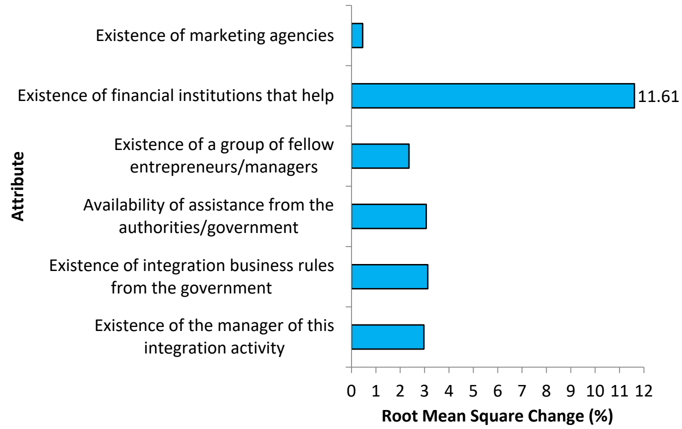

Fig. 7: Leverage of institutional attributes

organic fertilizer, and waste management best practices; (4) collaboration could increase knowledge, resources, and scaling potential through public-private partnerships involving the commercial sector, NGOs, and international organizations.

CONCLUSIONS

In conclusion, the sustainability index for environmentally low-input integrated farming that included activities of organic fertilizer, corn, and layer hen farming was determined using the MDS method. Furthermore, it considered factors affecting sustainability across five dimensions, namely environmental, social, economic, technological, and institutional dimensions. The sustainability index was estimated to be 86.10% (good sustainable), hence, the process had the potential for sustained development when the leverage factors described in each dimension were considered. These findings suggested that integrated farming comprising organic fertilizer, corn, and layer hen farming in the dry lands of the Pangkalan Lada sub-district had successfully integrated the potential of existing resources to realize sustainable agriculture and the potential to be applied in other locations in the future. Due to diverse regional characteristics, the developed sustainability index was valid and limited in the area where it was developed. The technological dimension had the lowest leverage value at 74.29%, while that of environmental, social, economic, and institutional were determined at 83.45%, 93.57%, 90.57%, and 88.39% respectively. Therefore, efforts to enhance the sustainability of these agricultural activities must primarily focus on the technological dimension, with an emphasis on 1) the potential for increasing integration production, 2) the availability of integration industry facilities, and 3) the level of specialization required for managers of the people's integration industry. Improving the economic aspects was prioritized, particularly those related to getting raw materials for the integration system. Support from the local government in obtaining raw materials was essential to maintain integrated farming. In terms of the environmental dimension, enhancing water during egg and fertilizer production and electric efficiency during production and marketing were essential factors. In the social dimension, addressing factors, such as job security, community engagement, and knowledge levels of workers and managers was identified as crucial for achieving sustainable implementation. Strategies, such as retraining, stakeholder engagement, communication, and capacity-building were deemed essential for promoting community well-being and fostering sustainable low-input integrated farming. For the institutional dimension, it was highly significant compared to other attributes, indicating that financial institutional support had a substantial impact on the sustainability of low-input integrated farming. Furthermore, it was emphasized that government support and technological considerations were essential for promoting environmentally low-input integrated farming in Indonesia, specifically given the escalating demand for producing egg and organic fertilizers using an integrated farming approach.

AUTHOR CONTRIBUTIONS

E. Widjaja prepared the manuscript, and critically analyzed the manuscript's crucial substantive value; B.N. Utomo performed recognition of data, and experimental operation; A.D. Santoso prepared the manuscript and critically analyzed the manuscript's crucial substantive value; Y.P. Erlambang performed recognition of data and handed material and operational support; Surono supervised manuscript preparation; M.A. Firmansyah prepared the manuscript, and critical revisions; S. Handoko performed recognition of data; E. Erythrina performed data curation; M.N. Rofiq performed experimental operate, and elaboration of MDS data; D. Iskandar performed prepared the manuscript and critically analyzed the manuscript's crucial substantive value; N.A. Sasongko recognized data and information and critically analyzed the manuscript's crucial substantive value; T. Rochmadi performed recognition of data; N. Abbas performed the literature review; M. Hanif performed recognition data and prepared the manuscript; Y.S. Garno prepared the manuscript; F.D. Arianti prepared the manuscript and made critical revisions; N.D. Suretno performed recognition data; M. Askinatin performed recognition data and prepared the manuscript; C.O.I. Hastuti performed administrative tasks; M. Fachrodji handed material and operational support.

ACKNOWLEDGMENTS

The authors are appreciative to all survey respondents for submitting data and engaging in heated discussion about organic fertilizer production operations and the growth of the Indonesian integrated agriculture system business. Acknowledgments are also conveyed to Sutiyana as the Chairman of KUD Tani Subur and Sartono as the chairman of CV Tani Subur who supports the implementation of this agricultural integration activity in the field.

CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

ABBREVIATIONS

%	Percent
AAS	Atomic Absorption spectrometry
C	Carbon
Ca	Calcium
Cu	Cupper
d	Euclidian distance
d_{ij}	Euclidian distance from point i to point
d_{ijk}	Squared distance
Fe	Iron
FGD	Focus group discussions
ISPO	Indonesian sustainable palm oil
K	Potassium
KUD	Village cooperative units
LEISA	Low external input sustainable agriculture
MDS	Multidimensional scaling
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium

N	Nitrogen
OC	Organic carbon
P	Phosphorus
Pb	Lead
pH	Potential of hydrogen
K	Potassium
R^2	Coefficient of determination
Rapfish	Rapid appraisal for fisheries, an analytical method to assess the sustainability of fisheries based on a multidisciplinary approach
RMS	Root mean square, a frequently used measure of the differences between values
RPJMN	National Medium-Term Development Plan
RPJPN	National Long-Term Development Plan
RSPO	Roundtable on Sustainable Palm Oil
SQR	Structured query reporter, a programming language designed for generating reports from database management systems
SR2	Squared correlation
S	Sulphurous
x-axis	Horizontal number line
y-axis	Vertical number line
Zn	Zinc

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HOW TO CITE THIS ARTICLE

Widjaja, E.; Utomo, B.N.; Santoso, A.D.; Surono.; Erlambang, Y.P.; Firmansyah, M.A.; Handoko, S.; Erythrina, E.; Rofiq, M.N.; Iskandar, D.; Sasongko, N.A.; Rochmadi, T.; Abbas, N.; Hanif, M.; Garno, Y.G.; Arianti, F.D.; Suretno, N.D.; Askinatin, M.; Hastuti, C.O.I.; Fahrodji, F., (2024). Sustainability index analysis for environmentally low-input integrated farming. Global J. Environ. Sci. Manage., 10(2): 537-556.

DOI: 10.22035/gjesm.2024.02.08

URL: https://www.gjesm.net/article_708351.html