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MULTIDIMENSIONAL ANALYSIS SUSTAINABILITY OF CORN-SOYBEAN INTERCROPPING MODEL IN SMALLHOLDER OIL PALM REPLANTING

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ABSTRACT

In the global agricultural sector, corn-soybean intercropping offers significant long-term benefits for increased productivity, improved agroecology and land management. While the impact of intercropping on corn and soybean yields has been studied extensively, information on their sustainability is limited. This study aims to analyse the status and sustainability determinants of the intercropping model on smallholder oil palm land through multidimensional analysis which includes economic, social, cultural, environmental, technological and institutional dimensions. Utilising a multi-dimensional scaling method with RAPFISH's modified software, called Rapid Appraisal for Palm Oil. The analysis results show that the sustainability index for oil palm plantations using the corn-soybean intercropping model has a good status in the economic dimension, with price-sensitive production attributes for smallholders. The value of the sustainability index in the socio-cultural dimension of good status with sensitive attributes of community access to replanting requirements. The continuous index value in the environmental dimension of the status is very good with the attribute of sensitive pest disturbance. The value of the sustainable index in the technology dimension is in good status with sensitive attributes of post-harvest handling. The value of the sustainable index in the institutional dimension is in good status with sensitive attributes of smallholder's group access to banking.

Keywords: corn, intercropping, palm oil, replanting, soybean, sustainability.

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INTRODUCTION

A model in which two or more crops are grown simultaneously or nearly simultaneously on the same farm in a regular cropping pattern is called intercropping. Intercropping is the new green revolution because it can improve land efficiency by using information on how species complement each other and provides a way to achieve sustainable intensification of agriculture (Xu et al., 2020). It has become the best cropping system for corn-soybean and plays an important role in contributing to

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modern and sustainable agriculture. Chang et al. (2020) stated that intercropping can increase crop competitiveness and improve resource utilisation on a given farm. Intercropping corn-soybean land is an effective and sustainable model. It is more effective than monocropping (Ren et al., 2017). This model can utilise soil nitrogen and other minerals and convert them from inorganic to organic forms that can be used for soil uptake. This increase in size can improve nitrogen production and resource availability (Li et al., 2013). With low-input and corn-soybean intercropping model provides significant benefits to smallholders (Iqbal et al., 2019).

Oil palm plantations in Indonesia have a strategic role in the economy as a source of foreign exchange (Purnomo et al., 2020), employment (Puder, 2019) and improving community welfare (Ayompe et al., 2021). Oil palm plantation land in Indonesia in 2022 has an area of 16.83 million hectares and 36.58% of this area is oil palm smallholder plantation. Riau Province has the largest area of oil palm plantations at 3.49 million hectares, of which 1.8 million hectares are smallholder plantations (Directorate General of Plantations, 2022).

Oil palms exceed economic value at 25 years of age (Afifah et al., 2021) and after 25-30 years, the trees are felled due to reduced oil content (Nuryawan et al., 2022). Oil palm productivity can be increased through replanting (Syarfi et al., 2019). The problem for smallholders to finance oil palm replanting because it requires large capital. Smallholders lose their income during the immature period of oil palm (0-3 years) (Triastutik & Hartati, 2020). Corn-soybean intercropping model programmes can address the loss of income during replanting (Rachman et al., 2022).

Nasution et al. (2022) showed that the application of the corn-soybean intercropping model on oil palm land is quite successful. The intercropping model can ameliorate the negative impact of oil palm on soil physic-chemical properties (Dhandapani et al., 2020). Although this model is considered to replace lost income, corn-soybean intercropping still needs to be analysed for sustainability in oil palm replanting programmes. Overall, conducting a sustainability analysis of corn-soybean intercropping in an oil palm replanting programme within an agricultural enterprise system is economically viable, environmentally friendly, and socially beneficial. This holistic approach can contribute to the long-term sustainability and resilience of agricultural communities.

Corn-soybean intercropping is expected to be a sustainable solution for smallholder oil palm replanting models. To date, no information or research shows the sustainability status of the corn-soybean intercropping model on oil palm replanting land specifically. The application of the concept of sustainability of the corn-soybean intercropping model has not been formulated with appropriate and measurable indicators, both in the context of policy, and its overall impact comprehensively. This study aims to analyse the index, status and determinants of the sustainability of the corn-soybean intercropping model in smallholder oil palm plantations, as well as policy strategies to address its sustainability.

MATERIALS AND METHODS

Description of Study Area

The research was conducted at a pilot location of corn-soybean intercropping in smallholder oil palm replanting land from January to December 2019. It is in Bukit Jaya Village, Ukui District, Pelalawan Regency, Riau Province with coordinates of 00°09′35.2″S and 102°06′23.5″E at an altitude of 44 m above sea level. The research site was on dryland that had been planted with oil palm for one cycle (25 years). It has Ultisol soil type with soil characteristics in certain parts such as acidic and organic soil, brackish groundwater, rather high humidity with an air temperature of 21.6°C-34.8°C, average rainfall of 151.33 mm, and rainy days of 9.5 mm/day (Badan Pusat Statistik Kabupaten Pelalawan, 2023).

Sampling and Data Collection

This research was conducted using a survey method, namely research to obtain facts, identify problems, and obtain justification for ongoing practices by certain units at a place and time with a sample. The selection of respondents is adjusted to the surrounding environmental conditions and understanding of the problem being researched. In this study, the selection of respondents using the purposive sampling method, also known as judgmental sampling, is a non-probability sampling technique used in research to select participants based on certain characteristics or qualities relevant to the study. A total of 50 respondents were selected with the criteria in which 35 respondents were smallholders as programme participants, administrators and Village Unit Heads and 15 respondents from the expert team with the criteria of having expertise in accordance with the field under study. Some considerations in determining the experts used as respondents are:

a) Have competent experience in the field studied.
b) Have a reputation or position that is competent in the field being researched.
c) Have high credibility and willingness and are in the location under study.

The data collected in this study was through (1) a literature review on corn-soybean intercropping and oil palm replanting, identifying key sustainability factors, (2) a field survey on economic, socio-cultural, technological, environmental and institutional components, and (3) development of a sustainable intercropping management model based on the analysis results.

Data Analysis

Analysis of the index and sustainability status of intercropping models in smallholder oil palm plantations using multi-dimensional scaling method (MDS) analysis techniques, assisted by the Rapid Appraisal for Fisheries (RAPFISH) add Ins Microsoft Office Excel application called RAP-PALM OIL (Rapid Appraisal for Palm Oil) approach. RAP-PALM OIL was modified to evaluate the sustainability of overlapping models on smallholder oil palm plantations from the RAPFISH approach developed by the University of British Colombia, Canada to assess the sustainability of fisheries (Kavanagh & Picher, 2004). RAPFISH software was used to define each measurable indicator. A multidimensional scale is a statistical technique that attempts to reduce the dimensions in a dataset by dividing it into simpler groups. Each dimension has properties that indicate sustainability (Akhmad & Suzy, 2005).

Multidimensional scale analysis (MDS) is carried out in several stages, namely, (1) determination of parameters covering five aspects (economic, social cultural, environmental, technological and institutional), (2) evaluation of each attribute based on sustainability criteria in each measurement, (3) ordination of analysis of sustainability index values, (4) to identify sensitive variables that affect sustainability, a sensitivity analysis was conducted and (5) to consider aspects of uncertainty is down with Monte Carlo analysis (Kavanagh & Picher, 2004).

The results of the MDS analysis will obtain (1) the status or index of each dimension and (2) sensitive attributes or influential attributes based on the root mean square (RMS). The normalisation test for model feasibility uses the determination coefficient (R^2), if the R^2 value is close to 1 the model is said to be good, or it means that the data is normally distributed. The feasibility test of the model is carried out to determine whether it is necessary to add attributes to the model and test the accuracy of the model compared to the actual situation. Meanwhile, leverage analysis is to find sensitive attributes or influential attributes that affect the sustainability index value in each dimension referring to the highest RMS value.

The ordinance analysis process in the form of index values, errors may occur so it is necessary to evaluate the influence of errors on the process so that it is necessary to carry out Monte Carlo simulations as a test of validity and accuracy. If the Monte Carlo simulation results do not change significantly or have a small difference in ordination values, it can be concluded that the ordination results have been able to overcome the random error (Pitcher et al., 2001). The simulation also serves to see the level of stability of the ordinance results. Monte Carlo simulation is a method to analyse the propagation of uncertainty where the goal is to determine how random variations or errors affect the sensitivity, performance, or reliability (consistency) of the system being modelled (Rubinstein, 1981).

The sustainability index value from the data processing ranges from 0 to 100 and is divided into four sustainability categories. The sustainability assessment index used in this study is shown in *Table 1*. A visualisation of the research flow chart describing the stages and steps can be seen in *Figure 1*.

TABLE 1. SUSTAINABILITY INDEX VALUE

Index category	Value
0.00-25.00	Unsustainable
25.01-50.00	Less sustainable
50.01-75.00	Sustainable enough
75.01-100.00	Sustainable

Source: Kavanagh and Pitcher (2004).

RESULTS AND DISCUSSION

The results of the MDS analysis presented in *Table 1*, indicate that the index values and sustainability statuses of the economic, social cultural, technological and institutional dimensions fall within the moderately sustainable category, with an average value ranging from 56.23-65.22. Conversely, the environmental dimension is classified as highly sustainable, with an index of 85.31. A visualisation depicting the sustainability statuses across dimensions is provided in a kite diagram (*Figure 2*). Furthermore, *Table 2,* presents the results of the comparison between the MDS analysis and Monte Carlo values.

The difference between the MDS sustainability index and the Monte Carlo analysis shown in *Table 2* is deemed acceptable as a predictor of the sustainability index value if it falls below 5% (Pitcher, 2013). Specifically, the disparity between the sustainability index value and the Monte Carlo value ranges from 0.96-4.13, which suggests that the RAP-PALM OIL model, employed for evaluating the sustainability of the corn-soybean intercropping models on oil palm replanting land, is highly accurate and justifiable. Mahida et al. (2019) stated that the difference between MDS and

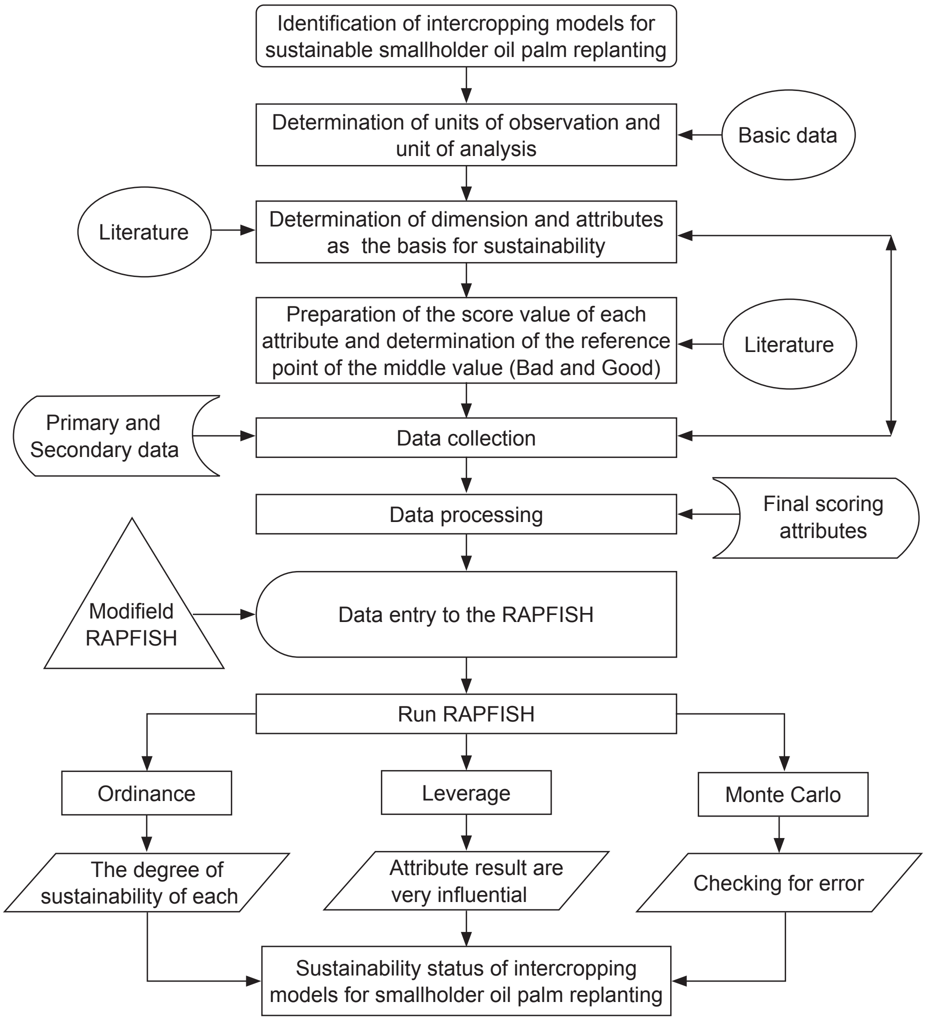

Figure 1. Stages of sustainability analysis of the intercropping model in the community oil palm replanting.

Monte Carlo results shows the confidence interval of the RAP-PALM OIL results. If the difference between MDS and Monte Carlo is smaller than the value of 1, then the resulting index is more than 90% accurate. If the results of the Monte Carlo analysis do not change significantly or have a small difference in ordination values, it can be concluded that the results of MDS coordination have been able to overcome the existence of random errors (Pitcher, 1999).

The percentage difference between the MDS and Monte Carlo is greatest in the environmental dimension 4.13, while the smallest difference occurs in the technological dimension 0.96. The high value of the environmental dimension is due to overlapping improving soil physical, chemical and biological properties, reducing surface erosion and increasing soil pH.

The results of the sensitivity analysis on each attribute are the determinants of the sustainability of the multi-state model of intercropping corn-soybean on oil palm replanting land. The results showed that of the 63 attributes analysed, 12 attributes influenced the corn-soybean intercropping model on oil palm replanting land. Key attributes were farm-gate prices and family labour (economic); access to replanting, empowerment and infrastructure (socio-cultural); pest infestation and soil type (environmental); post-harvest handling (technological); and bank access, land use consistency and ownership (institutional).

Economic Dimension

The results of corn-soybean overlap in oil palm replanting areas based on the economic dimension fall into the moderately sustainable category with an index of 60.02 (*Figure 3*) at a coefficient of determination (R^2) of 95% (*Table 2*). These results indicate that the economic dimension is a good model and can capture the problems that occur. Therefore, there is no need to add attributes to address the actual situation. The results of the Monte Carlo simulation of economic status show a value of 58.83 (*Table 2*), which indicates that there are no significant errors associated with the economic dimension.

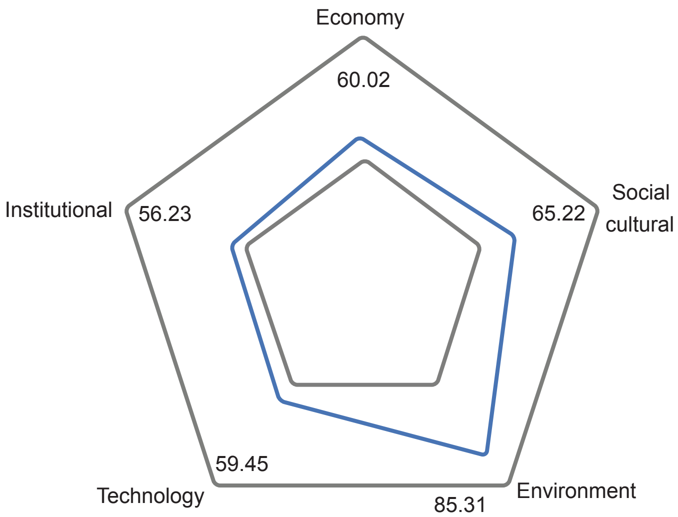

Figure 2. Inter-dimensional sustainability analysis kite diagram.

TABLE 2. INDEX AND SUSTAINABILITY STATUS OF INTERCROPPING MODEL IN REPLANTING SMALLHOLDERS' OIL PALM PLANTATIONS

Dimensions	R^2	Index ordination	Categories	Simulation Monte Carlo	Difference between indices and Monte Carlo
Economy	0.95	60.02	Sustainable enough	58.83	1.98
Social culture	0.94	65.22	Sustainable enough	64.08	1.75
Environment	0.95	85.31	Sustainable	81.79	4.13
Technology	0.94	59.45	Sustainable enough	58.88	0.96
Institutional	0.94	56.23	Sustainable enough	54.77	2.60

The results (*Figure 3*) of the leverage analysis show that there are two sensitive attributes out of 15 attributes forming the economic dimension that affect the sustainability of corn and soybean overlap on smallholder oil palm replanting land, namely the price of production at the farm level Index 3.82 and the adequacy of family labour for farming Index 3.44.

This study found that the selling prices of corn and soybean are lower than the government price. The selling price of corn at the farm level ranges from USD0.24-USD0.29/kg, which is lower than the government price of USD0.31. Likewise, the selling price of soybeans at the farm level is USD0.43/kg, lower than the standard price set by the government at USD0.53/kg. This is due to the lack of access to price information by the smallholders, cooperation not being well established, middlemen playing a dominant role, and markets being located far from smallholders. If this situation is not addressed immediately, it is feared that it will greatly affect the sustainability of the agricultural system.

Strategies to increase selling prices at the farm level can be done by ensuring that information on market prices of food crops and horticultural commodities reaches smallholders by providing information services, strengthening the function of village unit cooperatives as price stabilisers. According to Villanoa et al. (2019), the creation of good and easy market access and support for pricing policies that do not harm smallholders will be a factor in the successful development of agricultural enterprises.

The adequacy of family labour for agriculture is very limited with a RMS value of 3.44. This is due to the absence of family members at the farm location on account of continuing their education or working outside the area. The use of simple technology on intercropped land can overcome labour limitations. Effendi et al. (2014) stated that to overcome labour limitations and efforts to increase agricultural productivity, post-harvest technology and the development of agricultural mechanisation can be carried out.

Social Cultural Dimensions

The results of the social-cultural ordination analysis in the sustainability of corn-soybean intercropping for oil palm replanting land showed an index dimension of 65.22 with

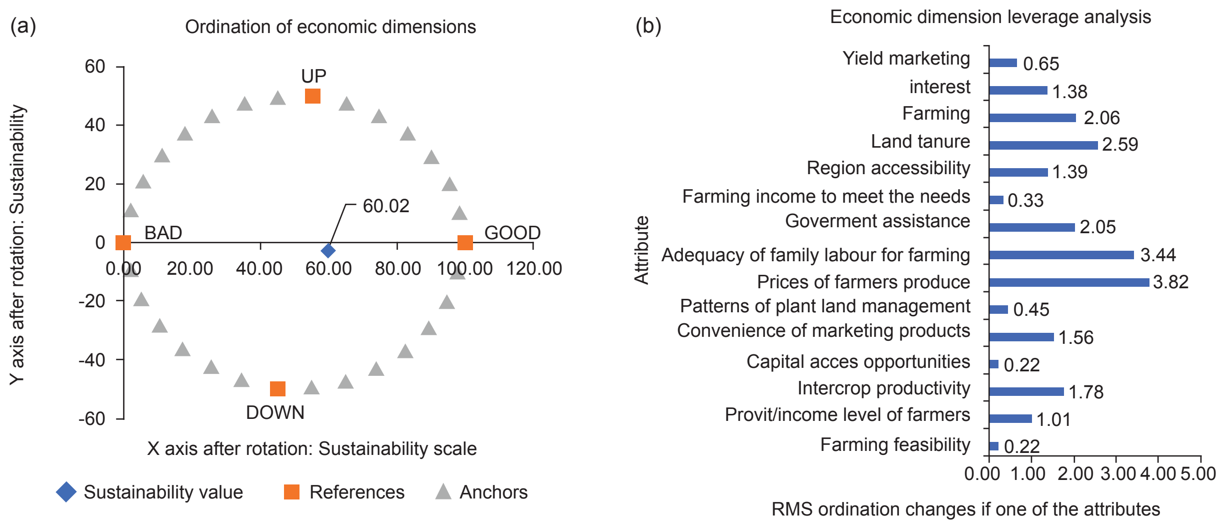

Figure 3. (a) Ordination index and (b) sensitive attributes of the sustainability status of corn-soybean intercropping in the economic dimension.

the category of sustainable enough (*Figure 4*). Similarly, the coefficient of determination was 94% and the Monte Carlo analysis status value was 64.08 (*Table 2*), which indicates that there is no significant disturbance in the absence of disturbance associated with social and cultural dimensions.

The results of the leverage analysis (*Figure 4*) identified three sensitive attributes out of 13 attributes of the socio-cultural dimension affecting community access to replanting requirements (RMS 5.17), community empowerment (RMS 4.71) and community access to replanting infrastructure (RMS 4.18). Based on the 2016 Minister of Agriculture Regulation on general guidelines for oil palm replanting (Directorate General of Plantations, 2022), 14 requirements must be met to participate in replanting and the process takes a long time. In addition to the requirements, there are still many procedures that must be followed before verification at the stage of land replanting, which must pass verification at the district and provincial levels, therefore, it is necessary to convey the regulation of replanting to smallholders more broadly.

A sensitive attribute in the empowerment of farming communities is the suboptimal role of extension workers as a companion to smallholders in groups to improve skills, applying technological innovations and decision-making. This is related to limited intellectual abilities that are not in accordance with field conditions. To reduce the impact of sensitivity on the strategies carried out, it is necessary to conduct technical skills training for smallholders to produce products when utilising productive land, improve the performance of assistants, improve the performance of smallholder groups and encourage cooperation.

Regarding the issue of community accessibility to replanting infrastructure, in this case especially inputs in the form of certified superior seeds and subsidised fertilisers, the strategy is to convey to the community the availability of certified superior oil palm seeds, the characteristics of superior seeds and how to obtain quality seeds and fertilisers. Good cooperation within smallholder groups and supported by adequate infrastructure will create a resilient and sustainable local food system (Lutz et al., 2017).

Environmental Dimensions

Intensive agriculture can have negative impacts on the environment such as the greenhouse effect, toxic gas release, soil erosion and environmental degradation (Yang et al., 2021). One of the efforts to reduce these negative environmental impacts is intercropping (Dhandapani et al., 2020). This result is with the regulation of the sustainability of corn-soybean intercropping on oil palm replanting land based on the environmental dimension which has an index of 85.31 with a very sustainable category (*Figure 5*). The coefficient of determination was 95% and the Monte Carlo simulation analysis value obtained was 34.20 (*Table 2*).

In *Figure 5*, the leverage analysis results showed two sensitive attributes that are influential factors, namely pest nuisance (RMS 6.83) and soil type (RMS 6.66). Pest infestations that occur in the research location are domesticated animals such as pigs and cows. An effective way to deal with pig pests has not yet been invented, and cow owners are advised not to freely release their livestock. Other pests were not found, so the use of pesticides in this area is very low. This is certainly very good for the safety of the food produced. According to Ademola et al. (2019), if such excessive inputs endanger food production,

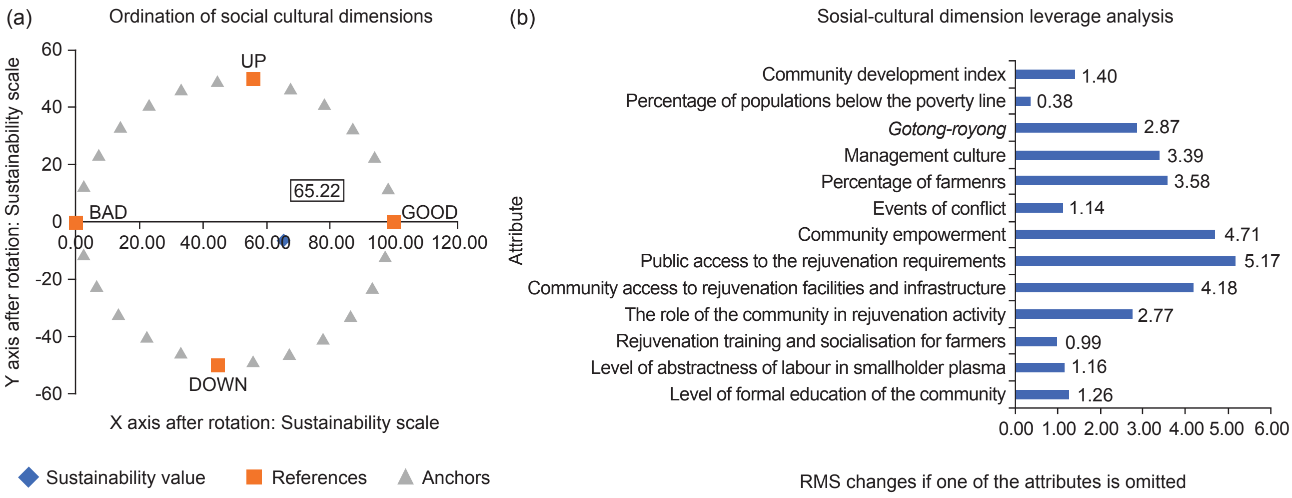

Figure 4. (a) Ordination index and (b) sensitive attributes of the sustainability status of corn-soybean intercropping in the socio-cultural dimension.

food security is the basis of sustainable agriculture. Archer et al. (2018), argued that to realise the sustainability of agriculture in the long term, it is necessary to reduce the use of chemical pesticides and the implementation of an integrated pest control system.

The second influential factor is soil type due to low nutrient content and pH. The pH value at the replanting site was low because the soil was overturned during tree felling and land clearing. To raise the pH of the soil, lime was used before planting. The application of organic and inorganic fertilisers is beneficial in improving the physicochemical properties of the soil at the research site. To increase soil fertility and pH, lime was applied before planting (Bossolani et al., 2021), organic and inorganic fertilisers, and legume intercropping (Duchene et al., 2017).

Dimensions of Technology

The results of the ordination of the sustainable status of corn-soybean intercropping agriculture in oil palm replanting land in the technological dimension with an index value of 59.45 (*Figure 6*), the sustainable category with a determination coefficient value of 94% and a Monte Carlo simulation has a value of 58.88 (*Table 2*). In *Figure 6*, the results of the leverage analysis show that post-harvest handling (RMS 2.71) and processing opportunities (RMS 2.64) are sensitive attributes that affect the sustainability of corn-soybean intercropping on oil palm replanting land. Improving smallholders' knowledge of agricultural technology innovations is an important part of the innovation adoption process and smallholders' empowerment. Gershom et al. (2019) stated that in accelerating agricultural development, individual knowledge has an important meaning because knowledge can increase the ability to adopt new technologies in agriculture. Jayne et al. (2019) stated that the determinants of agricultural sustainability are the availability of capital, technology, and smallholders' knowledge. This is in accordance with research by Syahza et al. (2021), which stated that good skills and mastery of technology by smallholders will improve their agricultural performance while increasing their income.

The quality of corn and soybean yields is currently not optimal due to poor post-harvest handling. To overcome this, a drying warehouse that can handle large-scale harvesting is needed. In terms of marketing, the harvested corn production is processed in the form of peeled corn and sold directly to traders, while soybeans are sold to tofu and tempeh processors. To increase the selling price of these products, the government needs to aid in the form of simple corn processing facilities that can convert dried corn into granular corn ready for livestock consumption. This is expected to increase market uptake and increase the selling value of the product. This is in accordance with Villanoa et al. (2019), that the sustainability of agricultural businesses is not only the responsibility of smallholders but also government policy.

Institutional Dimension

Ordination result of the sustainability status of intercropping agriculture in oil palm community replanting areas show that the institutional dimension ordinance is quite sustainable with an index of 56.23 (*Figure 7*) with a determination coefficient of 94% and a Monte Carlo simulation status value of 54.77 (*Table 2*). In *Figure 7* the

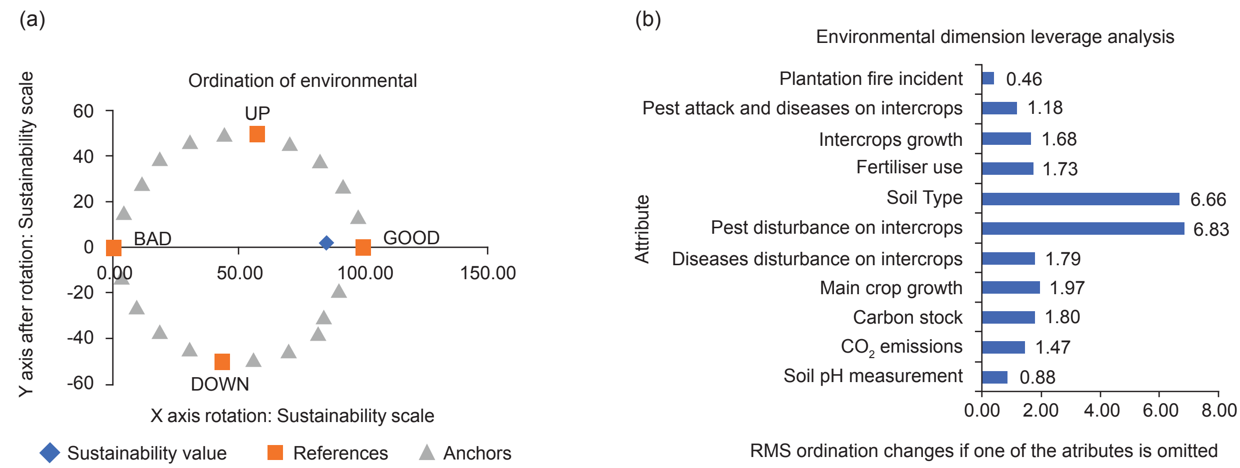

Figure 5. (a) Ordination index and (b) sensitive attributes of the sustainability status of corn-soybean intercropping in the environmental dimension.

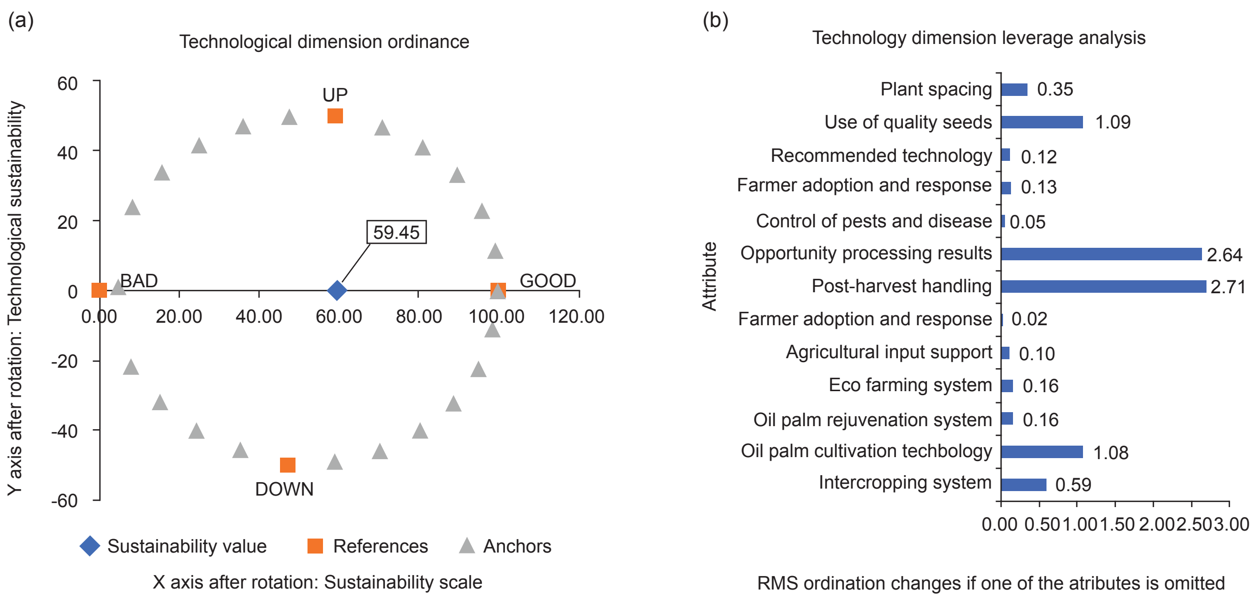

Figure 6. (a) Ordination index and (b) sensitive attributes of the sustainability status of corn-soybean intercropping in the technological dimension.

results of the leverage analysis show that in the institutional dimension, three sensitive attributes affect the 11 attributes analysed, namely, smallholders group access to banking (RMS 5.48), consistency of land use for plantation development (RMS 5.26) and land ownership status (RMS 4.72).

Policy Strategy for Sustainability of Intercropping Model

Sensitive attributes identified as key issues that can affect the sustainability of land regeneration in oil palm smallholdings need to be the focus of planning and problem-solving. The solution is the need for policy intervention against the influence of sensitive attributes that can improve the sustainability of oil palm plantation regeneration which is inseparable from various other related elements and resources, so a systematic and integrated approach is needed. This will prevent the phenomenon where one event or action triggers a series of similar events or chain reactions that will impact other aspects/dimensions and worsen land sustainability status regeneration in the oil palm plantation.

Based on the sensitive attributes that affect the viability of the corn-soybean intercropping model in oil palm replanting, a policy strategy is needed to address these sensitive attributes. There are 12 policy strategies to address the influence of sensitive attributes on each dimension as shown in *Table 3*.

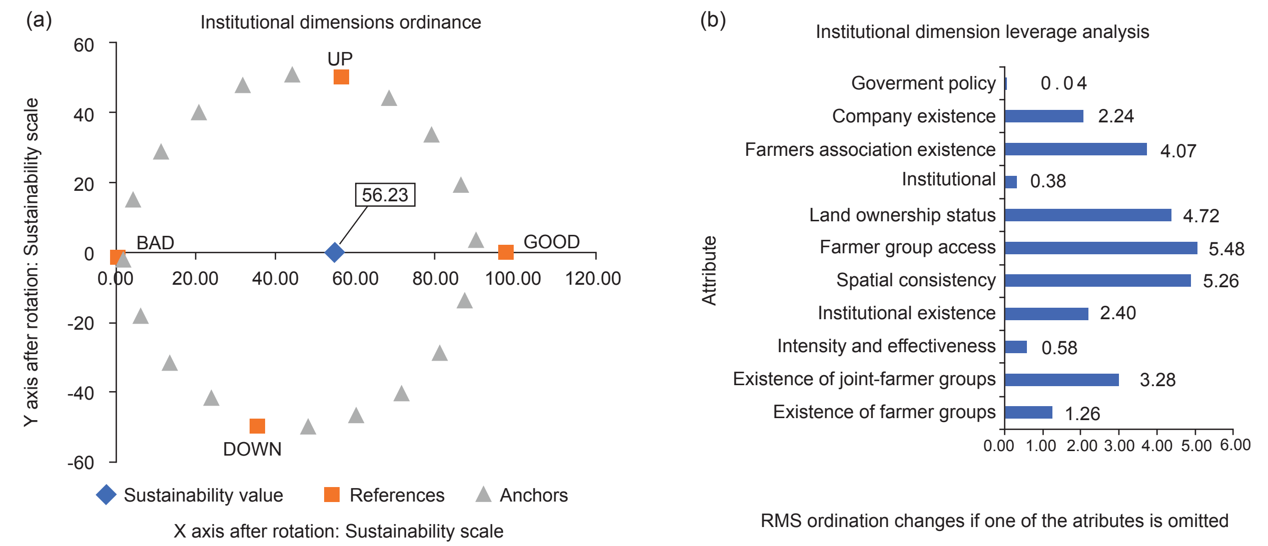

Figure 7. (a) Ordination index and (b) sensitive attributes of the sustainability status of corn-soybean intercropping in the institutional dimension.

TABLE 3. POLICY STRATEGY FOR INTERCROPPING MODEL IN OIL PALM REPLANTING AREAS

Dimensions	Sensitive attributes	Policy strategy
Economy	1. Yield at farm level	1. Improving access to market information on crop commodity benchmark prices.
	2. Sufficiency of family labour for farming business	2. Using simple farming tools for planting.
Social culture	1. Community access to replanting requirements	1. More widespread socialisation of the requirements and procedures for replanting oil palm smallholdings.
	2. Community empowerment	2. Training on intercropping cultivation techniques and other productive business.
	3. Community access to replanting infrastructure	3. Socialisation and information about the availability of superior seeds, characteristics of superior seeds, and fertilisers.
Environment	1. Intercrop pest infestation	1. Integrated pest control in collaboration with local village stakeholders.
	2. Soil type	2. The use of lime and organic fertilisers.
Technology	1. Post-harvest handling	1. Post-harvest handling/tools/facilities assistance.
	2. Result processing opportunities	2. Assistance with corn chopper.
	3. Smallholder groups' access to bank	3. Facilitate the transfer of smallholders's land certificates.
Institutional	1. Consistency of land use for plantation development	1. Coordinate with relevant ministries on the handling of forest plantations.
	2. Land ownership status	2. Coordinate with land agencies.

CONCLUSION

The sustainability of oil palm plantations with corn-soybean intercropping models is good in all dimensions. Economically, farm-level production prices are a key factor, requiring improved market access, smallholder cooperation and stronger village cooperatives. Socio-culturally, access to replanting programmes requires simplification and better outreach. Environmentally, pest control, especially for pigs, remains a challenge. In the technological dimension, post-harvest handling is critical and improving smallholders' knowledge on innovations can improve crop quality. Institutionally, better access to banking and financial literacy for smallholder groups is needed to improve loan management and the use of financial technology.

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