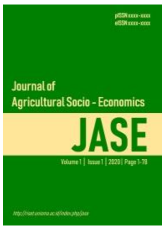

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Sustainability of Horticultural Farming in Purbalingga Regency: An Empirical Analysis Using Multidimensional Scaling

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Abstract. Horticultural crops are important commodities for supporting food needs and local economic development in Karangreja District, Purbalingga Regency. However, limited land availability, declining productivity, low farmer education, climate change, and pest attacks pose significant challenges to achieving sustainable farming. Unlike previous studies, which generally assess farming sustainability across ecological, economic, and social dimensions, this study integrates technological and institutional dimensions to provide a more comprehensive assessment. This study aims to assess the sustainability status of horticultural farming in Karangreja District across five dimensions: ecological, economic, social, technological, and institutional. A total of 97 farmers were selected as respondents through purposive sampling, and the data were analyzed using Multidimensional Scaling. The results show that overall sustainability falls into the moderately sustainable category, with an index value of 53.38. The ecological, economic, technological, and institutional dimensions are classified as moderately sustainable, with index values of 58.71, 54.72, 51.48, and 62.07, respectively. In contrast, the social dimension is classified as less sustainable, with the lowest index value of 39.93. These findings indicate that the sustainability of horticultural farming is relatively maintained but remains vulnerable in the social dimension. Therefore, policy interventions should prioritize farmer education, youth farmer regeneration, extension services, and institutional support to improve the long-term sustainability of horticultural farming.

Keywords: Horticultural Farming; Sustainability Assessment; Multidimensional Scaling; Social Dimension; Karangreja District.

INTRODUCTION

Food security refers to consistent physical, social, and economic access to sufficient, safe, and nutritious food that supports an active and healthy life (Pérez-Escamilla, 2024). Sustainable Development Goals (SDGs) 2 further emphasize the importance of ending hunger, reducing malnutrition, and strengthening sustainable agriculture through adequate policy and financing support (FAO et al., 2024). Indonesia's food security and food sovereignty agenda is closely related to food access, local food practices, and broader socio-economic structures, highlighting the importance of sustainable agriculture in strengthening long-term food systems (Dwiartama et al., 2023). The agricultural sector plays a strategic role in supporting sustainable food security. Agriculture plays a strategic role in providing food supplies, absorbing labor, and maintaining socio-economic stability (Dewi & Paramarta, 2025).

Sustainable agriculture represents an important component of sustainable development, emphasizing a balance among economic, social, and environmental aspects. (Nugraha et al., 2024). Sustainable agricultural development increasingly recognizes the importance of the horticultural subsector because horticultural commodities support food diversification, provide nutritional benefits, and create economic opportunities for smallholder farmers (Mukherjee et al., 2024). Furthermore, this subsector contributes significantly to agricultural development and the national economy, both by increasing the number of households that rely on horticultural farming for their livelihoods and by generating employment opportunities that improve community welfare (Rahayu et al., 2022). According to Statistics Indonesia of Central Java Province (2024), the total area of horticultural agricultural land in Central Java has continued to decline, from 636,158 hectares in 2020 to 509,080 hectares in 2023. Three major horticultural commodities experiencing significant decreases are cabbage, shallots, and cayenne pepper, as reported by the Direktorat Jenderal Hortikultura (2024).

Furthermore, data from Statistics Indonesia for Purbalingga Regency (2024) show that horticultural production has fluctuated, with Karangreja District contributing substantially to horticultural output. In 2022, Purbalingga Regency produced approximately 491,347 quintals of horticultural commodities annually across 18 districts. Among these, Karangreja District was the largest contributor. Data show that Karangreja District produced 473,402 quintals of horticultural commodities in 2022; however, this figure declined significantly to 315,352 quintals in 2024. The decline in productivity indicates inconsistency in the horticultural production system in Purbalingga Regency. Factors such as climate change, limited land availability, fertilizer management, and farmers' capacity to manage farming activities sustainably are suspected to be the main drivers of this fluctuation (Kharismawati & Karjati, 2021). Karangreja district has favorable geographic conditions and environmental temperatures for the cultivation of various highland crops. However, it is also one of the districts experiencing the largest decline in horticultural production within Purbalingga Regency. Vegetable commodities are the primary contributors to the reduction in horticultural output in the Karangreja district.

This situation may be caused by various factors, such as unstable soil quality, low adoption of technology by farmers, mismatches between production output and market demand, declining selling prices that do not align with production costs, and limited farmer participation in agricultural institutions (Leha, 2020). Agricultural productivity may also be affected by poor-quality farmland or underutilized land. At the same time, the demand for horticultural products is shaped by income growth, food prices, and increasing public awareness of the importance of fruits and vegetables in healthy diets (Harris et al., 2023). This decline in productivity poses a serious challenge, given that vegetable commodities play a crucial role in meeting the population's food and nutritional needs (Putri et al., 2022).

Based on a preliminary survey, horticultural farmers in Karangreja district, Purbalingga Regency, exhibit several characteristics that may affect the sustainability of their farming activities. Most farmers apply a combination of organic fertilizer and urea to crops such as cabbage, celery, and scallions, although many have not received government fertilizer subsidies. Farm gate prices are highly volatile, leading farmers to sell to intermediaries at lower profit margins. The majority of farmers are aged 25–50 years with education levels ranging from primary to junior secondary school. Although farmers demonstrate a reasonable understanding of sustainable farming practices through training programs, their participation in agricultural institutions remains low. Cultivation systems are semi-modern and heavily dependent on rainfall, while farm capital is typically sourced from personal funds from previous harvests. These findings indicate that horticultural farming in Karangreja is still largely traditional, which may hinder its long-term sustainability. Therefore, further research is needed to develop comprehensive farmer empowerment strategies to enhance the sustainability of horticultural farming in the area.

Sustainable farming requires an understanding of the various factors that influence successful production improvement. Previous studies, such as Wahyudi and Wulandari, (2019), Rasihen et al. (2020), Jamaludin et al. (2021), Ariandi (2022), Irani et al. (2024), and Suhartini et al. (2024) generally assess farming sustainability based on three main dimensions: economic, ecological, and social. These three dimensions essentially reflect the principles of sustainability, integrating economic feasibility, environmental conservation, and social equity as a foundation for formulating policies for horticultural farm management (Jamaludin et al., 2021). However, several studies indicate that these three dimensions do not solely determine farming sustainability. Technological and institutional factors also play a crucial role in improving the effectiveness and efficiency of agricultural systems. (Siregar et al., 2025). Adequate support for agricultural technology and strengthened institutional frameworks can enhance the sustainability of farming practices.

Previous studies on agricultural sustainability in Indonesia have applied multidimensional assessments covering ecological, economic, social, technological, and institutional dimensions

(Andriani et al., 2017; Leha et al., 2019; Jamaludin et al., 2021; Irani et al., 2024; Purnaditya, 2024). Therefore, assessing the sustainability of horticultural farming requires considering all five dimensions and their respective attributes to identify the key factors that determine the level of sustainability. Sustainability assessment tools are useful for identifying weak dimensions, comparing performance across sustainability aspects, and determining intervention priorities in agri-food systems (Doernberg et al., 2022). Accordingly, the novelty of this study lies in integrating technological and institutional dimensions into the sustainability assessment of horticultural farming, alongside the commonly used ecological, economic, and social dimensions. By applying Multidimensional Scaling, this study not only estimates the sustainability status of horticultural farming but also identifies the most sensitive attributes to prioritize in policy interventions. In addition, the Multidimensional Scaling approach is considered effective for identifying the sustainability status of horticultural farming in Karangreja District based on the attributes most sensitive to farming sustainability.

The reviewed theories and previous empirical studies indicate that horticultural farming sustainability should be assessed through multiple dimensions, including ecological, economic, social, technological, and institutional aspects. This study, therefore, aims to investigate: (1) the sustainability status of horticultural farming in Karangreja District, Purbalingga Regency, and (2) the dominant attributes influencing farming sustainability across the five dimensions. By applying Multidimensional Scaling, this study analyzes sustainability index values and identifies priority attributes to support the formulation of more targeted horticultural farming sustainability policies.

METHODS

Research Design and Data Collection

This study employed a quantitative descriptive approach to assess the sustainability status of horticultural farming in Karangreja District, Purbalingga Regency. This approach was used because the study aimed to measure sustainability index values and identify sensitive attributes across ecological, economic, social, technological, and institutional dimensions. Primary data were collected directly from horticultural farmers through structured interviews using a questionnaire. The questionnaire was developed based on sustainability attributes adapted from previous studies and adjusted to the local context of horticultural farming in Karangreja District. Each attribute was scored using a scale of 0–3 according to the scoring criteria established for each sustainability dimension. This study employs a quantitative descriptive approach, in which the data are expressed numerically and subsequently analyzed using Multidimensional Scaling (Siregar et al., 2025). This study uses primary data obtained directly from informants.

Population and Sample

The study population consisted of horticultural farmers in Karangreja District, Purbalingga Regency. Respondents were selected using purposive sampling based on several criteria: they worked primarily as horticultural farmers, had at least two years of farming experience, and operated privately owned farming businesses. Purposive sampling was used to ensure that the selected respondents had direct experience and sufficient knowledge of horticultural farming practices, enabling them to provide relevant information for assessing the sustainability of farming. The sample size was justified based on the need to obtain sufficiently precise information from a quantitative empirical study (Lakens, 2022). The minimum number of respondents was then calculated using the single-population proportion formula, with a 95% confidence level, a 10% margin of error, and an assumed population proportion of 0.5 (Egbuchulem, 2023).

Analytical Technique

This study applies the Rapid Appraisal for Fisheries (RAPFISH) approach based on Multidimensional Scaling, originally developed as a rapid multidimensional appraisal technique for evaluating sustainability status through ordination analysis (Pitcher & Preikshot, 2001). Although RAPFISH was initially developed for fisheries assessment, it has been adapted in this study to evaluate the sustainability of horticultural farming across ecological, economic, social, technological, and institutional dimensions (Pitcher et al., 2013; Purnaditya, 2024; Yusuf et al., 2021). The RAPFISH sustainability analysis was conducted through three main stages: (1) identifying the attributes for each sustainability dimension, (2) assigning scores to each attribute based on questionnaire data, and (3) calculating the sustainability index and status using ordination analysis, sensitivity analysis, and Monte Carlo analysis to test the uncertainty of the results. These stages enable the identification of the study area's sustainability level.

The Multidimensional Scaling method maps observed objects in a space based on their level of similarity: objects with similar characteristics are positioned closer together. In contrast, those with different characteristics are positioned farther apart (Nugraha et al., 2024). The sustainability assessment used five dimensions: ecological, economic, social, technological, and institutional. The attributes for each sustainability dimension, ecological, economic, social, technological, and institutional, were adapted from previous sustainability assessment studies on agricultural systems and adjusted to local horticultural farming conditions in Karangreja District (Widjaja et al., 2024; Dzikrillah et al., 2017; Zuhra et al., 2019). Each attribute was scored on a 0–3 scale, where higher scores indicate better sustainability performance. A summary of the dimensions and attributes is presented in Table 3, while detailed scoring criteria may be provided as supplementary material.

Table 3. Sustainability Dimensions and Their Attributes

Dimension	Number of Attributes	Attributes
Ecological	6	Agricultural land management; use of fertilizers and pesticides; crop quality; annual crop productivity; soil fertility; water availability
Economic	6	Price stability; horticultural productivity; cultivated land area; land ownership status; product selling price; marketing facilities
Social	6	Farmers' education level; average age of farmers; farmers' experience; frequency of extension services and training; farmers' perception of sustainability; farmers' perception of environmentally friendly technology
Technological	5	Level of technology adoption; level of technological mastery; soil cultivation practices; mulching practices; soil and water conservation technology
Institutional	6	Availability of marketing institutions; existence of farmer groups; frequency of farmer group meetings; availability of financial/marketing institutions; sources of farming capital; availability of microfinance institutions

The ordination test is used to determine the sustainability of farming activities by calculating a sustainability index. The sustainability index value is measured using a scale of 0–3, adjusted to each attribute (Zuhra et al., 2019). The categorization of the sustainability index value is determined based on sustainability value intervals. According to Siregar et al. (2025) , the sustainability scale is classified according to the following criteria**.**

Table 4. Sustainability Index Scale

Number	Index Value	Sustainability Status
1	0.00-25.00	Not sustainable
2	25.01-50.00	Less sustainable
3	50.01-75.00	Moderately sustainable
4	75.01-100.00	Highly sustainable

The sustainability index is determined by constructing a matrix X (n × p), where n denotes the number of dimensions and p the number of attributes per dimension. The attribute scores are subsequently standardized to ensure equal weighting across attributes, thereby minimizing differences in measurement scales. In the RAPFISH approach using Multidimensional Scaling, distances between points are calculated using the Euclidean distance, which represents the shortest straight-line distance in Euclidean space and is derived from the Pythagorean theorem (Leha et al., 2019).

The Monte Carlo simulation was conducted to evaluate the stability and uncertainty level of the Multidimensional Scaling analysis results by estimating the potential influence of errors within a 95% confidence interval. This analysis serves as a reliability test for the total sustainability index values across each dimension, which may be affected by procedural errors, misinterpretation of parameters, variations in scoring due to differing expert opinions, and the stability of the MDS analytical process. It also accounts for potential errors arising from incorrect data entry, missing data, or excessively high stress values (Leha et al., 2019). The stress value represents the degree of mismatch between the model and the observed data. The stress value indicates the degree of mismatch between the observed dissimilarities and the ordination configuration. Lower stress values indicate a better fit of the MDS model. In RAPFISH analysis, stress values below 0.25 are generally considered acceptable, indicating that the ordination results adequately represent the sustainability status. Meanwhile, stress values of 10–19.9% are categorized as sufficient, 5–9.9% as good, 2.5–4.9% as very good, and values below 2.5% are considered perfect in explaining the sustainability index (Yusuf et al., 2021). Lower stress values indicate a better balance between distance dissimilarities and the configuration map criteria, suggesting a more accurate representation of the sustainability status. The coefficient of determination (R^2) was used to assess the goodness-of-fit of the MDS ordination. Values closer to 1 indicate that the ordination configuration better represents the observed data.

Furthermore, leverage analysis, or sensitivity analysis, was employed to identify the attributes that have the greatest influence on the sustainability index within each dimension. The sensitivity of each attribute was assessed by changes in the Root Mean Square (RMS) value along the ordination axis. Attributes with higher RMS values were considered more sensitive because changes in these attributes produced greater changes in the sustainability index. In this study, the three attributes with the highest RMS values in each dimension were identified as the main leverage attributes, providing practical priorities for improving the sustainability of horticultural farming. Therefore, leverage analysis was used not only to identify sensitive attributes but also to determine priority factors for policy intervention and farm management improvement. According to Yusuf et al. (2021) The determination of the most sensitive attributes is based on RMS values that show significantly greater variation than those of other attributes within the same dimension.

RESULT AND DISCUSSION

The Sustainability Status of Horticultural Farming Enterprises

The results of the Multidimensional Scaling analysis across the five dimensions show that horticultural farming is moderately sustainable, with an index value of 53.38. This sustainability index was calculated by evaluating the elements that make up each of the five sustainability aspects. The stress levels for each dimension, as well as the average value, are below 0.25, indicating that the Multidimensional Scaling analysis produces better results when the stress in each sustainability dimension is lower. Furthermore, the coefficient of determination (R^2) for each dimension and its average value approaches 1, indicating that the indicators employed within each sustainability dimension accurately indicate horticultural farming's sustainability.

Table 5. Results of Stress Value and Coefficient of Determination (R^2) Analysis

Parameter	Ecology	Economics	Social	Technology	Institutional
Stress	0.19	0.19	0.19	0.17	0.18
R^2	0.87	0.89	0.88	0.94	0.91

Source: MDS analysis, 2025.

Based on the Monte Carlo Analysis across all dimensions, the overall sustainability index score is 53.38, indicating a moderately sustainable status. An examination of each sustainability dimension reveals that the institutional dimension demonstrates a relatively high level of sustainability. This finding is consistent with field conditions, where institutional factors, such as the widespread availability of farmer groups, have enhanced farmers' capacity to manage their farming activities. In contrast, the social dimension exhibits a lower index value and is therefore categorized as less sustainable. This condition is largely attributed to the predominance of aging farmers and the limited interest of younger generations in agricultural activities. Additionally, the relatively low level of education among farmers further constrains their capacity to manage horticultural farming enterprises effectively.

Table 6. Results of Monte Carlo Analysis for the Total Sustainability Index at the 95% Confidence Level

Dimensions	Multidimensional Scaling Results	Category
Ecology	58.71	Moderately Sustainable
Economics	54.72	Moderately Sustainable
Social	39.93	Less Sustainable
Technology	51.48	Moderately Sustainable
Institutional	62.07	Moderately Sustainable
Multidimension	53.38	Moderately Sustainable

Source: MDS analysis, 2025.

Table 6 shows that horticultural farming in Karangreja District is moderately sustainable, with an overall index value of 53.38. The institutional dimension recorded the highest index value, indicating relatively stronger institutional support, while the social dimension had the lowest value and was categorized as less sustainable. This result suggests that social aspects, particularly farmer education, farmer regeneration, and participation in capacity-building activities, require greater policy attention.

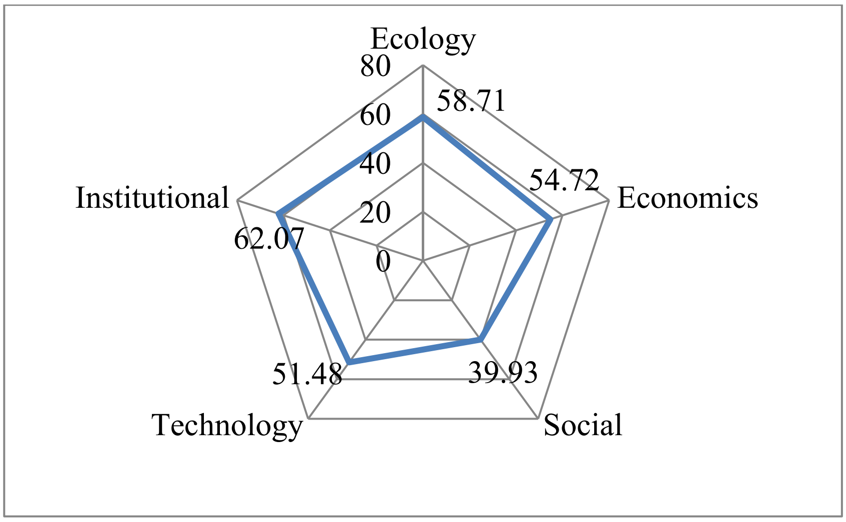

Figure 2. RAP Kite Diagram of Ecological, Economic, Social, Technological, and Institutional Dimensions

Figure 2 illustrates the relative sustainability performance of horticultural farming across the five dimensions. The institutional dimension shows the strongest sustainability performance, indicating that institutional support plays an important role in maintaining farming sustainability in Karangreja District. The social dimension, however, has the weakest sustainability performance and therefore requires priority intervention, particularly in improving farmer education, regeneration, and participation in capacity-building activities.

Sensitive Attributes Affecting the Sustainability of Horticultural Farming

A leverage analysis was conducted to identify the attributes most influential on the sustainability index of horticultural farming across the ecological, economic, social, technological, and institutional dimensions. The sensitive attributes were determined based on the highest RMS values, indicating that changes in these attributes would have a greater influence on the sustainability index. Therefore, these attributes represent priority areas for improving the sustainability performance of horticultural farming in Karangreja District.

Sensitive Attributes of the Ecological Dimension

The ecological dimension had a sustainability index of 58.71, indicating a moderately sustainable status. Figure 3 presents the leverage analysis results for the ecological dimension, showing that soil fertility (11.12), agricultural land management (10.77), and the use of fertilizers and pesticides (7.82) had the highest RMS values. These results indicate that the ecological sustainability of horticultural farming in Karangreja District is most sensitive to soil quality, land management practices, and input-use management.

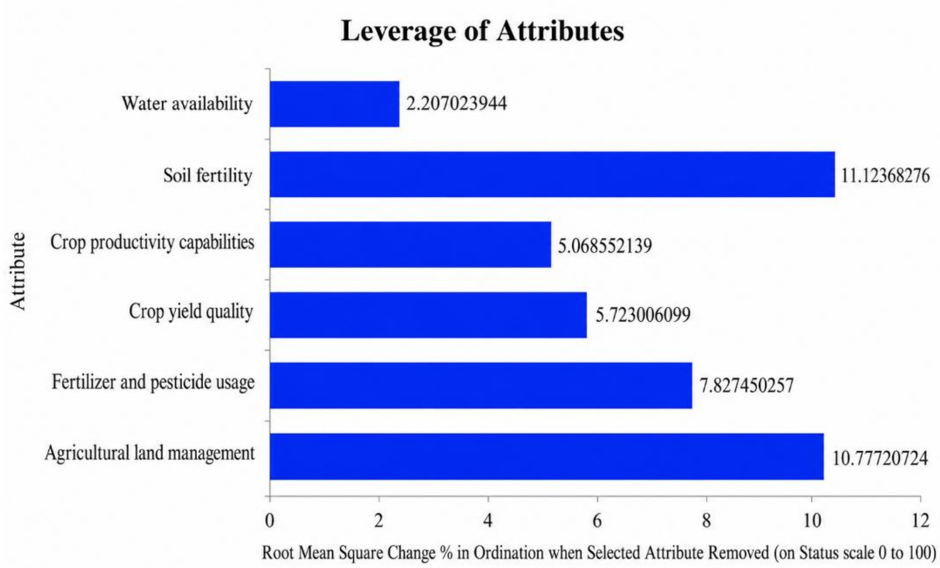

Figure 3. Leverage Analysis of Attributes in the Ecological Dimension

Soil fertility emerged as the most sensitive ecological attribute. This condition is closely related to the geographical characteristics of Karangreja District, which is located on the slopes of Mount Slamet and has a relatively cool climate that supports the cultivation of horticultural crops. Land suitability for appropriate commodities can increase crop productivity (Pawiengla et al., 2020). In addition to natural conditions, soil fertility is also supported by farmers' effective management of agricultural land, as reflected in the predominance of farmers with more than 10 years of farming experience. Such experience enables farmers to be better prepared and more skilled in managing horticultural farming activities (Triadi et al., 2022).

Agricultural land management also plays an important role in maintaining ecological sustainability. Farmers' long experience in farming contributes to their ability to manage land, adjust cultivation practices, and maintain production continuity. In the study area, land management practices are supported by the use of organic manure, particularly during the seedling stage. The use of organic inputs can improve soil quality and sustain agricultural practices (Leha et al., 2019).

The use of fertilizers and pesticides was also identified as a sensitive attribute. Farmers generally use organic manure as the primary input, while pesticides are applied only under specific conditions to control pests. For example, in spring onion cultivation, pesticides are used when leaf fungal diseases occur. This practice indicates that farmers attempt to control pests without excessive chemical input use, thereby supporting more environmentally friendly farming practices.

The attribute with the lowest leverage value in the ecological dimension was water availability (2.20). During the dry season, irrigation water is limited because the study area is in a highland region, and farmers rely heavily on rainfed systems. Climate change has also affected farmers' ability to manage rainfed agricultural systems, resulting in suboptimal production levels during the harvest period (Arief et al., 2025). In some cases, farmers use municipal water supply (PDAM) for irrigation during the dry season, which increases crop maintenance costs. Higher production costs can reduce production efficiency and decrease horticultural productivity (Arief et al., 2025). Therefore, strengthening irrigation infrastructure, water resource management, and efficient water conservation technologies is necessary to improve ecological sustainability and enhance farming system adaptation to climate uncertainty. Agricultural sustainability assessment requires attention to environmental indicators and local resource management conditions because ecological performance is strongly influenced by the capacity of farming systems to maintain soil quality, water availability, and adaptive resource-use practices (dos Reis et al., 2023).

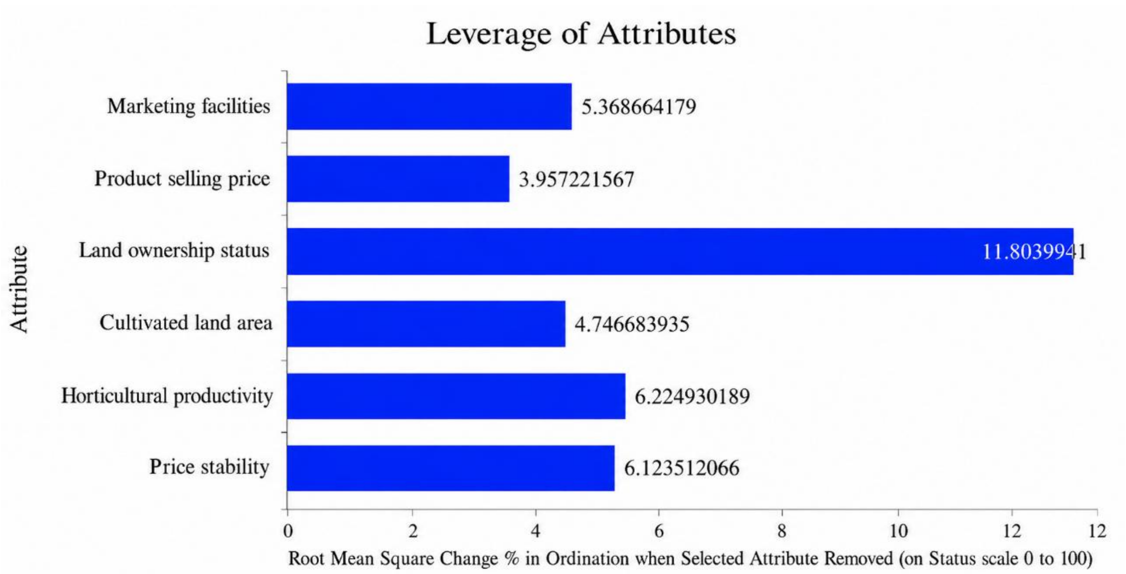

Figure 4. Leverage Analysis of Attributes in the Economic Dimension

Sensitive Attributes of the Economic Dimension

The economic dimension had a sustainability index of 54.72, indicating a moderately sustainable status. Figure 4 presents the leverage analysis results for the economic dimension, showing that land ownership status (11.38) and horticultural productivity (6.22) had the highest RMS values. These results indicate that the economic sustainability of horticultural farming in Karangreja District is most sensitive to farmers' control over production assets and their ability to maintain productivity.

Land ownership status emerged as the most sensitive economic attribute. Most horticultural farmers in Karangreja District cultivate privately owned land, with the majority of their agricultural land inherited from family members. A total of 90 farmers manage privately owned land without expanding their farming areas by purchasing additional land. This condition provides farmers with greater certainty in managing farming activities and reduces the potential risk of land ownership disputes, thereby supporting the sustainability of agricultural enterprises (Kharismawati & Karjati, 2021).

Horticultural productivity was also identified as a sensitive attribute in the economic dimension. The use of high-quality seeds improves the productivity of horticultural farming. Farmers generally obtain quality seeds from nearby agricultural input distributors. The availability of distributors supplying certified seeds increases farming efficiency by facilitating access to production inputs, ensuring seed quality, and reducing the time and costs associated with procurement (Pawiengla et al., 2020). These conditions support the continuity of cultivation activities and have the potential to enhance agricultural productivity.

The attribute with the lowest leverage value in the economic dimension was the product selling price (3.95). In general, the long-term selling prices of agricultural commodities in the study area are relatively stable. However, during the last three months, a decline in selling prices has been observed. This decline does not necessarily reflect structural price instability, but is more likely influenced by temporary factors, including decreased harvest quality, climate change, and rising production costs that are not accompanied by increases in selling prices (Arief et al., 2025).

This situation has been exacerbated by a prolonged dry season. In August, September, and November, which should typically mark the beginning of the rainy season, no rainfall occurred in the study area. Consequently, farmers had to undertake additional crop maintenance through irrigation using municipal water supply (PDAM), which increased production costs. Furthermore, in the past five months, a decline in crop yields has been observed (Pawiengla et al., 2020). This condition is reflected in a reduction in annual harvest outputs, with production of a single commodity that previously exceeded 2 tons decreasing to less than 1.5 tons. Therefore, improving economic sustainability requires strengthening productivity support, improving access to quality inputs, stabilizing marketing channels, and reducing production cost pressures faced by horticultural farmers.

Sensitive Attributes of the Social Dimension

The social dimension had a sustainability index of 39.93, indicating lower sustainability. Figure 5 presents the leverage analysis results for the social dimension, showing that farming experience (9.45) and farmers' perception of environmental sustainability (4.46) had the highest RMS values. These results indicate that the social sustainability of horticultural farming in Karangreja District is strongly influenced by farmers' accumulated farming knowledge, environmental awareness, and human resource capacity.

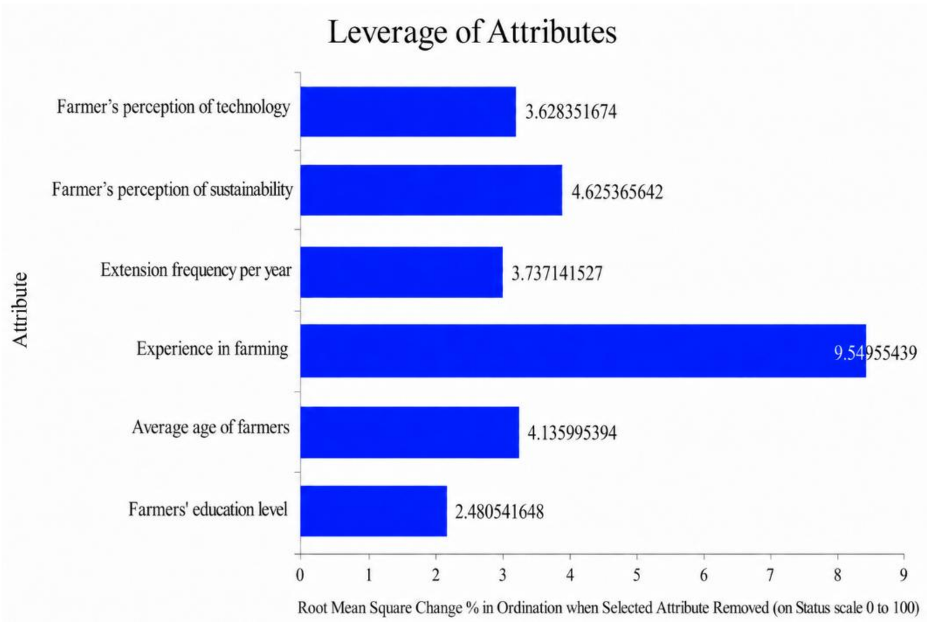

Figure 5. Leverage Analysis of Attributes in the Social Dimension

Farming experience emerged as the most sensitive attribute in the social dimension. Longer farming experience can strengthen farmers' practical knowledge, technical skills, and capacity to cope with production risks and future agricultural challenges (Wardani et al., 2025). Respondent data show that 58 farmers have been farming for more than 10 years, largely because many continue farming activities inherited from their parents. This experience provides a strong practical foundation for maintaining horticultural farming activities.

However, the dominance of experienced farmers also reflects a structural challenge in farmer regeneration. The declining interest of younger generations in agriculture may threaten the long-term sustainability of horticultural farming in Karangreja District if no effective regeneration occurs. This condition is largely attributed to farmers' children's tendency to prefer occupations perceived as less physically demanding, such as self-employment or entrepreneurship outside the agricultural sector (Saleh et al., 2021). Limited farming experience among younger generations can also reduce their interest in continuing agricultural activities (Naziah et al., 2023).

Farmers' perception of environmental sustainability was also identified as a sensitive attribute. In the study area, farmers' relatively positive environmental awareness is reflected in their continued use of organic manure as the primary nutrient source for maintaining soil fertility. Chemical fertilizers are generally applied only when crops approach harvest, and their use is often balanced with organic manure from livestock activities in the farming area. The continued dominance of organic manure use indicates farmers' awareness of environmental conservation (Susanto et al., 2022).

Nevertheless, this environmental awareness remains largely practical and experience-based, rather than being fully supported by a strong scientific understanding. Without knowledge-strengthening and capacity-building programs, farmers' environmental awareness may remain static and may not easily develop into more modern, efficient, and sustainable agricultural innovations (Nugrahapsari et al., 2020). Therefore, improving the social dimension requires not only preserving farmers' local knowledge but also strengthening education, training, and systems of innovation-based learning.

The attribute with the lowest leverage value in the social dimension was farmers' education level (2.48). On average, farmers have only completed basic education, which may influence their ability to adapt to rapid technological and agricultural developments (Wardani et al., 2025). However, farmers' knowledge is not obtained solely through formal education but also through participation in farmer groups (Fadillah et al., 2023). Therefore, more targeted interventions are needed, including practice-based training, stronger extension services, youth farmer regeneration programs, and technology-based learning systems to improve the long-term social sustainability of horticultural farming.

Sensitive Attributes of the Technological Dimension

The technological dimension had a sustainability index of 51.48, indicating a moderately sustainable status. Figure 6 presents the leverage analysis results for the technological dimension, showing that mulching practices (7.76) and soil and water conservation technology (6.26) had the highest RMS values. These results indicate that the technological sustainability of horticultural farming in Karangreja District is strongly influenced by farmers' ability to apply cultivation technologies that support resource efficiency, crop protection, and environmental conservation.

Mulching practices emerged as the most sensitive attribute in the technological dimension. Farmers commonly apply mulching techniques to horticultural crops such as tomatoes, chili, spring onions, cabbage, and celery to control weeds that may interfere with crop growth. The use of appropriate agricultural technologies can help reduce pest attacks and minimize disturbances to crop development (Purnomo et al., 2021). This finding indicates that practical cultivation technologies, such as mulching, play an important role in improving the efficiency and sustainability of horticultural farming.

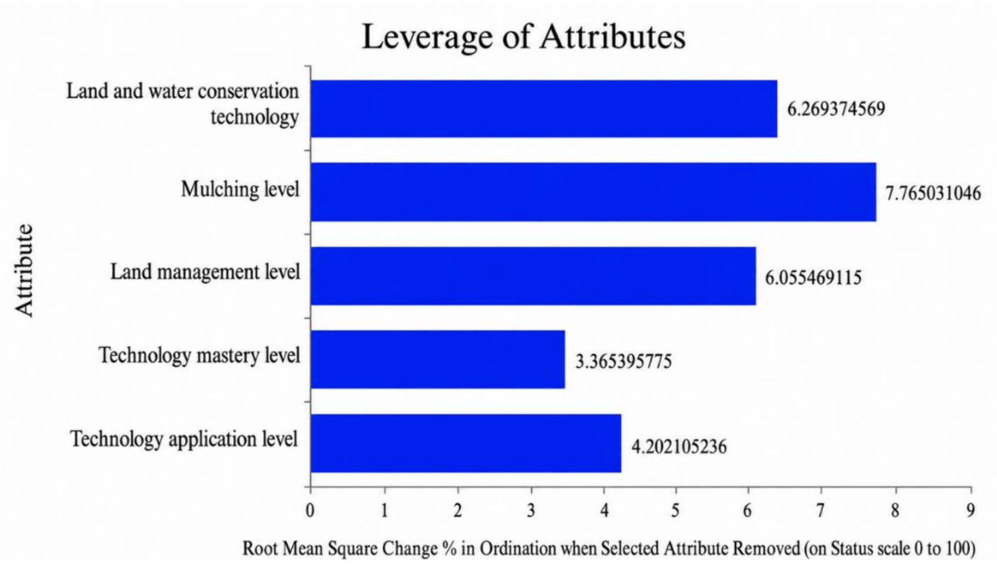

Figure 6. Leverage Analysis of Attributes in the Technological Dimension

Soil and water conservation technology was also identified as a sensitive attribute. Farmers use rainwater-harvesting systems as a natural irrigation method, particularly during the dry season when water is scarce. In addition, the limited and careful use of pesticides indicates that farmers have a relatively good understanding of soil and water conservation practices, which supports environmental sustainability (Susanto et al., 2022). These practices show that technological sustainability is closely related not only to modern equipment, but also to farmers' ability to adopt environmentally adaptive farming practices.

The attribute with the lowest leverage value in the technological dimension was technological mastery (3.36). Survey results indicate that 52 farmers have adopted modern technologies, including electric sprayers for pesticide application and diesel-powered irrigation pumps during the dry season. However, the adoption of agricultural technology remains relatively limited, as reflected in the low value of the technology adoption attribute. The limited ability of farmers to adopt agricultural innovations may be attributed to their relatively low level of technological mastery (Siregar et al., 2025).

Consequently, the use of agricultural technology in the study area remains limited and is often complemented by traditional tools, such as hoes and manual sprayers. This condition indicates that horticultural farming activities are still largely dominated by conventional cultivation methods with relatively low levels of mechanization (Siregar et al., 2025). Farmers' limited interest and capacity to use modern technologies may further constrain technology adoption (Fadillah et al., 2023). Therefore, improving technological sustainability requires practice-based training, demonstration plots, wider access to affordable adaptive technologies, and stronger extension support to increase farmers' technological mastery.

Sensitive Attributes of the Institutional Dimension

The institutional dimension had a sustainability index of 62.07, indicating a moderately sustainable status and the strongest of the sustainability dimensions. Figure 7 presents the leverage analysis results for the institutional dimension, showing that sources of farming capital (6.23), frequency of farmer group meetings (4.82), and the existence of marketing institutions (3.91) had the highest RMS values. These results indicate that farmers' access to capital strongly influences institutional sustainability in horticultural farming, the functioning of farmer groups, and the availability of market-related institutions.

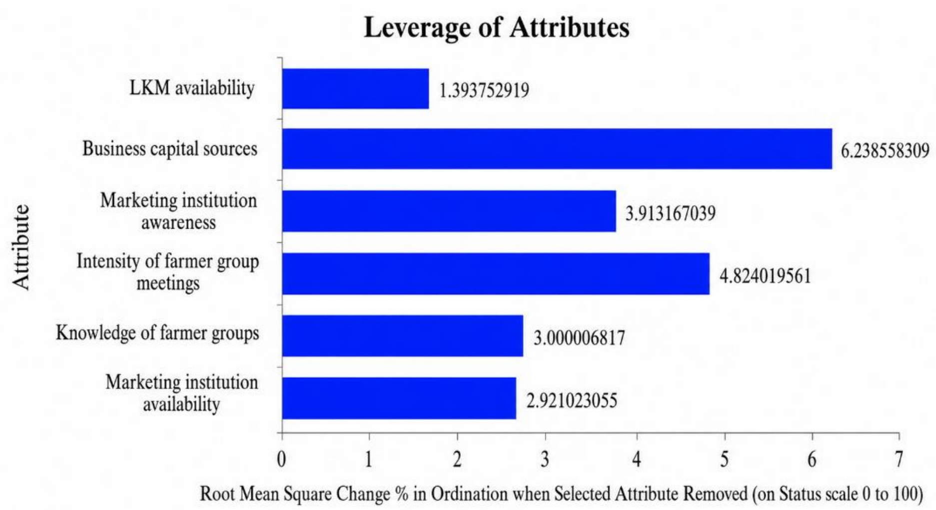

Figure 7. Leverage Analysis of Attributes in the Institutional Dimension

Sources of farming capital emerged as the most sensitive institutional attribute. The results indicate that horticultural farmers in Karangreja District generally rely on personal capital derived from previous harvest income to finance their farming activities. This condition reflects a certain degree of financial independence among farmers. However, reliance on personal capital may also create vulnerability, particularly when crop yields decline or production costs increase. In such situations, farmers may reduce the use of agricultural inputs or limit hired labor to minimize production costs. Therefore, improving access to formal and informal financing institutions is important to strengthen farmers' capacity to maintain production continuity.

The frequency of farmer group meetings was also identified as a sensitive institutional attribute. Farmer groups provide an important platform for farmers to exchange information, discuss cultivation problems, access agricultural innovation, and strengthen collective capacity. Regular farmer group meetings can improve farmers' knowledge of sustainable farming practices and enhance their ability to respond to production and market challenges (Handayani et al., 2019). Therefore, strengthening the roles and activities of farmer groups is essential to improving institutional sustainability.

The existence of marketing institutions also plays an important role in supporting institutional sustainability. In the study area, farmers commonly sell their horticultural products to local traders or intermediaries with whom they have established long-term relationships. Although this system may limit farmers' bargaining position, it also provides market certainty because farmers have regular buyers for their harvest. These relationships create mutually beneficial arrangements: farmers gain assurance that the market will absorb their products, while traders obtain a stable supply of horticultural commodities (Leha et al., 2019).

The attribute with the lowest leverage value in the institutional dimension was the availability of microfinance institutions (1.39). Survey results indicate that microfinance institutions are not yet available near the study area, limiting farmers' access to additional capital for farm expansion and technology adoption. Improved access to financial institutions can help farmers increase input use, improve production capacity, and enhance productivity (Yanda et al., 2019). Therefore, institutional sustainability should be strengthened by improving farmers' access to capital, market information, farmer organizations, and financial institutions that can support long-term horticultural farming sustainability (Abusiri et al., 2024)

CONCLUSION

This study concludes that horticultural farming in Karangreja District, Purbalingga Regency, is generally moderately sustainable. However, sustainability performance is not balanced across the five dimensions analyzed, as the social dimension is categorized as less sustainable and represents the weakest aspect of horticultural farming sustainability. This finding indicates that farming sustainability is not determined solely by ecological, economic, technological, and institutional conditions, but also strongly depends on the quality of human resources, farmer regeneration, education, and social capacity within farming systems.

The main contribution of this study lies in applying a five-dimensional sustainability assessment and identifying sensitive attributes through Multidimensional Scaling, thereby providing more specific intervention priorities for sustainable horticultural farming. The findings imply that policy interventions should prioritize strengthening farmer capacity through needs-based training, youth farmer regeneration, extension services, and farmer group empowerment. In addition, access to financial institutions and institutional support should be improved to help farmers manage production risks and sustain their farming enterprises in the long term. This study is limited to horticultural farmers in Karangreja District; therefore, future research should compare sustainability performance across different horticultural production centers and incorporate longitudinal data to examine changes in sustainability status over time.

Author Contribution

Sodik Dwi Purnomo contributed to the conception and design of the study, including the development of the research framework and formulation of the study concept. Alfit Budi Prasetyo contributed to data collection and data curation, ensuring that the research data were properly gathered, organized, and prepared for analysis. Noviati Aning Rizki Mustika Sari contributed to the analysis and interpretation of the research findings, including the examination of data patterns and the formulation of analytical insights. Damar Jati contributed to the writing of the manuscript, including the preparation of the initial draft and its revision. Tri Esti Masita and Heru Cahyo contributed to the final approval of the manuscript and took responsibility for the accuracy, integrity, and accountability of the scientific work.

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