

SUSTAINABILITY ANALYSIS OF POTATO FARMING IN GROGOL VILLAGE, PEJAWARAN DISTRICT, BANJARNEGARA REGENCY

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Abstract

Sustainable agriculture is an agricultural system that is ecologically viable (environmentally friendly), economically feasible, socially acceptable, and compatible with the local community's cultural values. Horticultural farming plays an important role in the Indonesian economy, with potatoes being one of its major commodities. Potato farming activities in Grogol Village provide a substantial contribution to the livelihoods of the local community. Furthermore, the geographical conditions of Grogol Village are highly supportive and well-suited for potato cultivation. This study aims to analyze the sustainability status of potato farming using the Rapfish method with a Multidimensional Scaling (MDS) approach. The research was conducted in Grogol Village, Pejawaran District, Banjarnegara Regency, based on three dimensions: economic, social, and ecological. A total of 93 farmers were selected as respondents using a purposive sampling method. The results indicate that the overall sustainability status falls within the moderately sustainable category, with a score of 56.75. The economic dimension is classified as moderately sustainable with a score of 57.23. The social dimension is also categorized as moderately sustainable with a score of 55.70. The ecological dimension is classified as moderately sustainable with a score of 57.23. Dimensions categorized as moderately sustainable should be maintained and further improved in order to achieve a highly sustainable status, thereby enhancing farmers' capacity to manage their agricultural enterprises.

Keywords: Sustainability, Horticulture, Multidimensional Scaling, Potato Farming, Potatoes

INTRODUCTION

The agricultural sector plays a crucial role in Indonesia's economic development as an agrarian country. In addition to serving as a provider of food supplies, this sector contributes to employment generation, income enhancement, and the provision of raw materials for various industrial sectors (Arrasyid, 2021). In national development, the agricultural sector serves as one of the main pillars in achieving food security and sustainable economic growth. Food security refers to a condition in which household food needs are adequately fulfilled, characterized by the availability of sufficient quantities of food, good quality, safety for consumption, equitable distribution, and accessibility for all segments of society (Muryono et al., 2020). According to the Food and Agriculture Organization (FAO) (2020), a country is considered to have stable food security when the average proportion of food expenditure among low-income households is approximately 40 percent. However, Indonesia's figure, which still reaches 46.45 percent, indicates that sustainable food security has not yet been fully achieved. In this context, the agricultural sector plays a strategic role as a provider of food supplies, an absorber of labor, and a supporter of social and economic stability within society (Nugrahapsari et al., 2021).

One of the agricultural subsectors that makes a significant contribution to the national economy is horticulture. In addition to contributing to the Gross Domestic Product (GDP), the horticultural subsector occupies a strategic position in national agricultural development (Putra et al., 2022; Mardial et al., 2020). Indonesia's large population as consumers of horticultural products

creates substantial market opportunities, both in terms of quantity and the continuously increasing demand for product quality each year (Kasmin et al., 2023). Among various horticultural commodities, potatoes are one of the leading commodities with high economic value, broad market opportunities, and continuously increasing demand for both household consumption and the food processing industry (Putra et al., 2022). Furthermore, potatoes have a relatively longer shelf life than many other horticultural commodities, making them highly potential for further development (Hardyastuti, 2018). The development of potato commodities should be carried out in accordance with the principles of sustainable agriculture. Sustainable agriculture is an implementation of the sustainable development concept that aims to manage natural resources wisely so that their benefits can be enjoyed by the present generation without compromising the ability of future generations to enjoy the same benefits (Suhartini et al., 2020). In line with this objective, the horticultural subsector constitutes an integral component of efforts to strengthen a sustainable national agricultural system.

Central Java Province is one of the main potato production centers in Indonesia, with the Dieng Highlands serving as the primary area for the development of this commodity (Nugrahapsari et al., 2021). According to data from Statistics Indonesia (Badan Pusat Statistik) (2023), potato production in Central Java reached 248,700 tons, distributed across 29 regencies, including Banjarnegara Regency. One of the potato-producing areas in the regency is Pejawaran District, which possesses considerable economic potential. According to the Agricultural Extension Center (Balai Penyuluhan Pertanian) of Pejawaran District, Grogol Village is one of the villages with the highest potato production in the area. Nevertheless, potato production over the last five years has exhibited considerable fluctuations. The increase in cultivated land area has not been accompanied by a consistent increase in production output. This condition is influenced by various factors, including climate change, pest and disease infestations, and the intensive use of chemical fertilizers and pesticides. These phenomena indicate that the potato production system in the area has not yet achieved full stability and requires the implementation of more sustainable agricultural practices (Pratiwi et al., 2018).

Agricultural productivity is also influenced by the quality of land used for cultivation activities. Declining land quality can lead to reduced agricultural productivity, which ultimately becomes a serious challenge because horticultural commodities play an important role in meeting the food and nutritional needs of society (Amalia et al., 2016). Based on the results of a preliminary survey, potato farmers in Grogol Village exhibit characteristics that may influence the sustainability level of their farming operations. Most farmers still rely on chemical fertilizers because they are considered more practical and capable of providing rapid plant growth responses. However, a positive trend has emerged, as some farmers have begun transitioning to more environmentally friendly cultivation systems. The majority of farmers belong to the productive age group of 25–60 years and have educational backgrounds predominantly ranging from elementary school to junior high school. Although farmers' understanding of sustainable agricultural practices remains relatively limited, most have participated in agricultural extension programs and training activities. These findings indicate that the potato farming system in Grogol Village is still largely dominated by traditional cultivation practices, which may hinder long-term sustainability. Therefore, further research is required to formulate farmer empowerment strategies capable of enhancing the sustainability of farming operations in the area.

The implementation of sustainable agriculture requires a comprehensive understanding of the various factors influencing the success of agricultural production systems. Previous studies, such as those conducted by Quraini et al. (2023), Suharti et al. (2024), Leha (2020), Septarianes et al. (2020), Nawangsari et al. (2022), and Rasihen et al. (2021), have demonstrated that agricultural sustainability is generally evaluated based on three principal dimensions: economic, social, and ecological dimensions. These three dimensions reflect the fundamental principles of sustainable development, which integrate economic viability, environmental conservation, and social equity in the management of horticultural farming enterprises (Jamaludin et al., 2021). Nevertheless, several

studies have shown that agricultural sustainability is not solely influenced by these three dimensions. Other factors, such as agricultural technology support and institutional strengthening, also play important roles in enhancing the sustainability of agricultural systems.

Therefore, Grogol Village was selected as the research location. This selection was based on the significant role of potato production in supporting community food needs, as potatoes constitute an important staple food commodity whose production needs to be enhanced to strengthen food security within the community (Anisa et al., 2022). Accordingly, this study aims to determine the sustainability status of potato farming and to identify the sensitive attributes that influence the achievement of a sustainable agricultural or farming system.

LITERATURE REVIEW

Farm management is a field of study that examines how individuals can allocate available resources effectively and efficiently with the objective of generating profits within a specific period (Amili et al., 2020). Farm management also concerns how individuals utilize production factors, including land and surrounding natural resources, as capital in the most optimal manner. Farming activities may include both crop cultivation and livestock production. From an economic perspective, agricultural production is viewed as a process of managing inputs to generate outputs (Ibrahim et al., 2021). Based on the definitions above, it can be concluded that farm management is closely related to the utilization of resources to generate income. A farming enterprise is considered successful when it is able to meet its obligations, including the payment of capital interest, the maintenance of equipment used, wages for hired labor, and other production inputs, as well as obligations to third parties, while maintaining the continuity of the enterprise (Ratnawati et al., 2020).

As an alternative approach, sustainable farming offers an environmentally friendly system that balances productivity, natural resource conservation, and the welfare of farmers and surrounding communities. Through agricultural systems based on land conversion management, agroecology, and crop diversification, sustainable agriculture has the potential to increase productivity without degrading natural ecosystems. By adopting organic farming practices, farmers can maintain soil fertility and water quality while reducing negative environmental impacts (Farooq et al., 2019). Nevertheless, the adoption of sustainable agriculture continues to face various challenges, including limited farmer knowledge, restricted access to technology, and inadequate policy support. Sustainable agriculture is essential for achieving food security. Syarifullah et al. (2022) emphasized that agricultural sustainability consists of three main components, namely the ecological, economic, and social dimensions. Based on the definitions and concepts discussed above, it can be understood that the core principle of sustainable agriculture is the effective management of resources in agricultural activities to improve environmental quality while ensuring the continuity of production.

Agricultural development plays a strategic role in the formation of the national economic system. The contribution of farmers is reflected in various aspects, including capital formation, food provision, the supply of industrial raw materials, animal feed and bioenergy production, employment generation, foreign exchange earnings, and the provision of environmentally friendly resources (Wahyuni et al., 2023). The government's role in agricultural development includes implementing community empowerment programs aimed at reducing poverty, particularly in rural areas. Agricultural development and rural development are inseparable components of the same process. To this day, the agricultural sector continues to play an important role in supporting the national economy (Sahara et al., 2023).

The success of potato farming is influenced by development initiatives that support sustainable cultivation systems. Supporting aspects such as the adoption of technology, the efficient use of production inputs, irrigation systems, and farm management practices need to be developed effectively. These efforts are directed toward increasing agricultural production to meet

domestic food and industrial demands, enhancing export performance, increasing farmers' incomes, expanding employment opportunities, and promoting equitable business opportunities (Rumaelan et al., 2025).

RESEARCH METHODS

This study employed a descriptive and quantitative approach, in which data were expressed in numerical form and subsequently analyzed using Multidimensional Scaling (MDS) (Susanto et al., 2022). Primary data were collected through surveys and direct interviews with farmers using structured questionnaires. The research was conducted in Grogol Village, Pejawaran District, Banjarnegara Regency. The study population consisted of farmers residing in Grogol Village. Samples were selected using a purposive sampling method, and the sample size was determined using the Slovin formula, resulting in a total of 93 respondents (Assidiki et al., 2021). The sustainability analysis was conducted using the Rapfish approach through three main stages: (1) identifying the attributes of each sustainability dimension, (2) assigning scores to each attribute based on questionnaire data, and (3) calculating the sustainability index and sustainability status using ordination analysis, sensitivity analysis, and Monte Carlo analysis to assess the uncertainty of the results. These stages enabled the identification of the sustainability level of farming systems in the study area.

The Multidimensional Scaling (MDS) method is an analytical technique used to map objects based on the degree of similarity among their characteristics. Objects with similar characteristics are positioned closer together, whereas objects with different characteristics are located farther apart (Dzikirillah et al., 2017). The attributes of the economic, social, and ecological dimensions were determined through modifications of the frameworks proposed by Suharti et al. (2024), Rahmah et al. (2024), Leha et al. (2019), and Zuhra et al. (2019), and were further adjusted based on field observations and interviews. Subsequently, each attribute was assigned a score according to the indicators established for each sustainability dimension, as follows:

Table 1. Sustainability Dimensions and Their Attributes

Dimension	Attribute	Score	Good	Bad	Scoring Creteria
Economic	Farming income (Suhartini et al., 2024)	0;1;2;3	2	0	(0) very low, insufficient; (1) low, sufficient for daily needs; (2) sufficient, needs are met well; (3) high, needs are met and there is some left over for saving
	Ease of marketing/marketing access (Rahmah et al., 2024)	0;1;2;3	3	0	(0) very difficult, cannot sell the harvest; (1) quite difficult, often encounter obstacles; (2) quite easy, can sell the harvest even though there are obstacles; (3) very easy, sell the harves
	Access capital (Suhartini et al., 2024)	0;1;2;3	3	0	(0) very difficult to obtain capital; (1) difficult and limited; (2) quite easy,

	Production cost (Rahmah <i>et al.</i> , 2024)	0;1;2;3	2	0	sometimes available; (3) easy, sufficient capital is available according to needs (0) High costs are difficult to cover expenses; (1) Costs are quite high, profits are limited; (2) Costs and harvest results run smoothly; (3) Costs are relatively small compared to results
	Land productivity (Leha <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) Hasil panen rendah, sehingga tidak layak jual; (1) Hasil panen cukup, tetapi banyak kerusakan; (2) Hasil panen baik, kerusakan relatif sedikit; (3) Hasil panen tinggi, dalam kondisi baik
	Selling price (Leha <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) very unprofitable; (1) less profitable; (2) quite profitable, covering costs and profits; (3) very profitable, high and stable profits
	Tingkat pendidikan petani (Suhartini <i>et al.</i> , 2024)	0;1;2;3	3	0	(0) very difficult, cannot sell the harvest; (1) quite difficult, often encounter obstacles; (2) quite easy, can sell the harvest even though there are obstacles; (3) very easy, sell the harvest
Social	Farmer education level (Suhartini <i>et al.</i> , 2024)	0;1;2;3	3	0	(0) very low, no schooling; (1) low, only elementary school; (2) secondary education; (3) high, more education

	Family welfare (Suhartini <i>et al.</i> , 2024)	0;1;2;3	3	0	(0) very poor, difficult to meet needs; (1) not prosperous; (2) quite prosperous, needs are met; (3) prosperous, all needs are met
	Extension activities (Suhartini <i>et al.</i> , 2024)	0;1;2;3	3	0	(0) not useful; (1) less useful, gained little knowledge; (2) quite useful, some knowledge was applied; (3) very useful, knowledge was applied and results increase.
	Involvement of farmer groups (Suhartini <i>et al.</i> , 2024)	0;1;2;3	3	0	(0) never participated in activities, 0 times; (1) rarely participated in activities, 1-2 times; (2) quite often participated in activities, 3-4 times; (3) very often participated in activities, 5 times or more.
	Household health level (Zuhra <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) very often, conflict occurs once a season; (1) often, several times a season; (2) conflict rarely occurs; (3) there is never any conflict
	Intensity of land conflicts (Leha <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) does not support the wish, some family members are sick; (1) less supportive, some family members are unhealthy; (2) quite supportive, some family members are healthy; (3) supports the wish, family members are healthy
Ecological	Use of pesticides or fertilizers (Leha <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) do not use; (1) rarely, use only occasionally; (2) use regularly but not excessively; (3) very often, use every growing season

Agricultural land management (Leha <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) very poor management, not sustainable; (1) poor management, not yet environmentally friendly; (2) quite good, implementing sustainable agricultural practices; (3) very good management implementing environmentally friendly principles
Pest and disease control (Zuhra <i>et al.</i> , 2019)	0;1;2;3	2	0	(0) never done; (1) rarely done; (2) quite routinely done; (3) very routine
agricultural land conversion (Leha <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) land conversion is very high; (1) land conversion occurs frequently; (2) land conversion occurs rarely; (3) no land conversion occurs and the land is maintained
Quality of crop yields (Zuhra <i>et al.</i> , 2019)	0;1;2;3	3	0	(0) very low quality; (1) low and limited quality; (2) sufficient quality and acceptable to the market; (3) high quality, and meets broad market standards
Condition and availability of clean water (Suhartini <i>et al.</i> , 2024)	0;1;2;3	3	0	(0) very limited, dirty, very difficult to use; (1) limited or less clean; (2) partially available; (3) available, clean and sufficient throughout the season

Ordination analysis was used to determine the sustainability status of potato farming based on the sustainability index values obtained. The index values were calculated using a scale ranging from 0 to 3 according to the attributes analyzed (Zuhdi *et al.*, 2021). Furthermore, sustainability levels were categorized based on sustainability value intervals referring to Siregar *et al.* (2025). The classification of sustainability status is presented as follows.

Table 2. 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

Each scored attribute was subsequently standardized to equalize the weights among attributes and reduce differences in measurement scales. In the Rapfish method based on Multidimensional Scaling (MDS), the distance between points was calculated using Euclidean distance, which represents the shortest straight-line distance between two points in a multidimensional space and is based on the Pythagorean Theorem (Leha et al., 2019).

Simulasi Monte Carlo digunakan untuk menguji kestabilan dan tingkat ketidakpastian hasil Monte Carlo simulation was employed to evaluate the stability and uncertainty level of the Multidimensional Scaling (MDS) analysis results at a 95% confidence level. This analysis serves as a reliability test of the sustainability index, which may be influenced by procedural errors, differences in scoring, inaccuracies in parameter interpretation, or data entry errors (Leha et al., 2019). In addition, the quality of the MDS ordination results was assessed using the stress value, which indicates the degree of fit between the model and the observed data. A stress value below 20% is considered adequate for representing sustainability conditions. The lower the stress value obtained, the better the model fit to the data, resulting in more accurate sustainability analysis outcomes (Yusuf et al., 2021).

The coefficient of determination (R^2) is the square of the correlation coefficient and is used to indicate the proportion of data variability that can be explained by the Multidimensional Scaling (MDS) process. This value reflects the degree of correspondence between the model and the observed data. The coefficient of determination ranges from 0 to 1 (or 0–100%), where values closer to 1 indicate that the model is capable of explaining the data with a higher level of accuracy. In general, an R^2 value greater than 0.5 is considered good, whereas values ranging from 0.2 to 0.3 are still regarded as acceptable depending on the context and objectives of the analysis.

RESULTS AND DISCUSSION

3.1 Sustainability Status of Potato Farming

The results of the Multidimensional Scaling (MDS) analysis across the three dimensions indicate that potato farming falls within the moderately sustainable category, with a sustainability index value of 56.72. This value was obtained based on the assessment of various attributes representing the economic, social, and ecological dimensions. The stress values for each dimension, as well as their average value, were below 0.25, indicating a good level of model fit. Furthermore, the coefficient of determination (R^2) values for each dimension and their average were close to 1, suggesting that the selected attributes were able to accurately explain the sustainability conditions of potato farming.

Table 3. Results of Stress Value and Coefficient of Determination (R^2) Analysis

Parameter	Economics	Social	Ecology
Stress	0,16	0,16	0,15
R^2	0,93	0,93	0,93

Source: *Multidimensional Scalling* (2010), 2026

Berdasarkan hasil simulasi Monte Carlo pada tingkat kepercayaan 95%, diperoleh hasil bahwa nilai indeks keberlanjutan yang dihasilkan melalui analisis Multidimensional Scaling (MDS) menggunakan perangkat lunak Rapfish tidak menunjukkan perbedaan yang signifikan. Hasil tersebut mengindikasikan bahwa tingkat keandalan dan konsistensi analisis yang dilakukan cukup baik, sehingga nilai indeks keberlanjutan yang diperoleh dapat dipercaya.

Table 4. Results of Monte Carlo Analysis for the Total Sustainability Index at the 95% Confidence Level

No	Dimensions	Multidimensional Scaling Results	Category
1	Ecology	57,23	Moderately Sustainable
2	Economics	55,70	Moderately Sustainable
3	Social	57,23	Moderately Sustainable

Source: *Multidimensional Scaling* (2010), 2026

Based on the results of the Monte Carlo simulation at a 95% confidence level, the sustainability index values generated through the Multidimensional Scaling (MDS) analysis using the Rapfish software showed no significant differences. These findings indicate that the reliability and consistency of the analysis were satisfactory, suggesting that the resulting sustainability index values can be considered trustworthy.

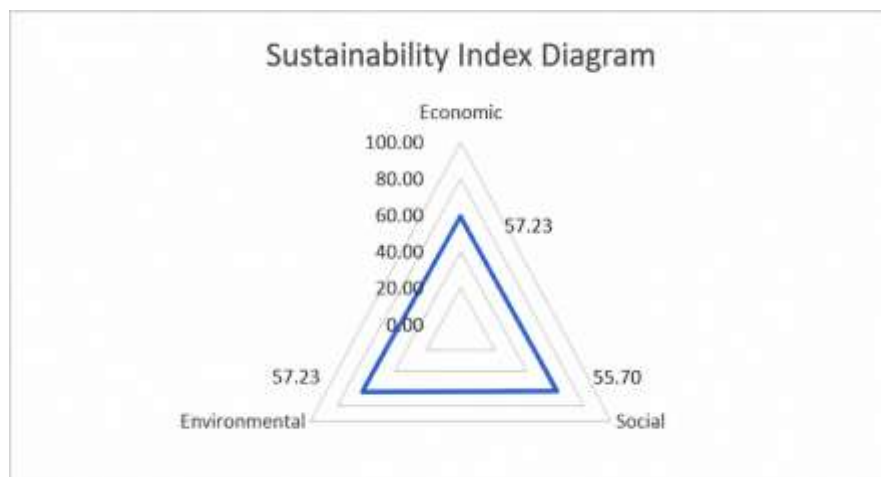


Figure 1. RAP Kite Diagram of Economic, Social, Ecological

Based on the sustainability index values in each dimension, the kite diagram illustrates the relative sustainability levels of all dimensions. The economic, social, and ecological dimensions show relatively higher sustainability indexes, indicating better sustainability performance.

3.2 Sensitive Attributes Influencing the Sustainability of Potato Farming

3.2.1 Sensitive Attributes of the Economic Dimension

The economic dimension of sustainability was assessed using the Multidimensional Scaling (MDS) method based on several key attributes: agricultural income, market access, capital access, production costs, land productivity, and selling prices. These attributes were chosen because they represent economic factors that play a crucial role in supporting the sustainability of horticultural agriculture. The MDS analysis results showed a sustainability index value for the economic

dimension of 57.23. This value falls into the moderate sustainability category, with an index range of 50.01–75.00. This finding indicates that the economic conditions of potato farming are relatively favorable and capable of supporting agricultural sustainability, although several aspects still need improvement to ensure long-term sustainability. To assess the reliability of the MDS results, a Monte Carlo analysis was conducted at the 95% confidence level. This analysis aims to identify potential errors or uncertainties in data processing and analytical procedures. The Monte Carlo simulation results were then compared with the MDS analysis results to determine the degree of difference between the two approaches. Based on the Rapfish analysis, the difference between the MDS and Monte Carlo index values was 0.78, or less than 1. This very small difference indicates that the analytical process is quite stable and exhibits a low level of estimation error. Next, a sensitivity analysis was conducted to identify the attributes that have the greatest impact on the economic dimension's sustainability score. Sensitive attributes are important because changes in these attributes will have a greater impact on the sustainability index. The results of the sensitivity analysis for the economic dimension are presented in the following figure.

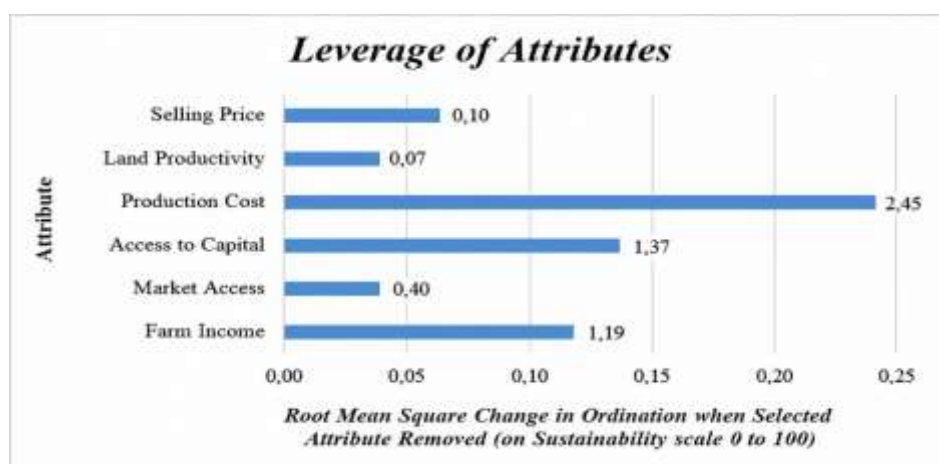


Figure 2. Leverage Analysis of Attributes in the Economic Dimension

The values of sensitive attributes can be used to improve the sustainability index of the economic dimension through efforts aimed at enhancing these attributes. Three attributes within the economic dimension were identified as being sensitive to the sustainability index of potato farming, namely production costs (2.45), access to capital (1.37), and farm income (1.19). Production costs in the study area are influenced by expenditures on fertilizers, pesticides, and labor, all of which require substantial financial resources during each planting season. Among these cost components, labor constitutes the largest expenditure, particularly in land preparation activities that require a considerable amount of labor. Consequently, farmers must allocate greater financial resources to meet the requirements of potato cultivation so that farming activities can be carried out optimally. This condition contributes to the high production costs incurred during a single growing season (Ikhsan et al., 2024). In addition to high production costs, access to capital also determines the level of farm income. Farmers with better access to capital are generally more capable of purchasing agricultural inputs and adopting more modern farming equipment (Rasidi et al., 2025). Therefore, adequate access to capital and stable potato commodity prices are essential factors in increasing farmers' income. Favorable and relatively stable selling prices can enhance income while simultaneously strengthening the sustainability of potato farming enterprises managed by farmers (Trisna et al., 2023).

Meanwhile, the attribute with the lowest leverage value in the economic dimension was market access (0.04). In general, market access for agricultural commodities in the study area is

influenced by the low selling price of potatoes at the farm level, which is caused by the lengthy marketing chain and the limited authority of farmers in determining marketing access. Typically, farmers sell their produce to middlemen, who subsequently sell it to retailers, and retailers then sell it to consumers (Chauhan et al., 2019). This condition is largely attributed to farmers' limited knowledge of market access, resulting in agricultural marketing activities that continue to be dominated by intermediaries (brokers) who act as links between farmers and the market. Consequently, brokers tend to maintain stronger relationships with traders and buyers, possess a better understanding of market structures, and have more direct access to agricultural markets. Therefore, it is necessary to strengthen and secure agricultural supply chains in order to increase product selling prices, enabling potato farmers to obtain more optimal profits. Such efforts can be achieved through training programs and by improving market accessibility so that farmers become less dependent on middlemen and brokers (Magesa et al., 2020).

3.2.2 Sensitive Attributes of the Social Dimension

The sustainability analysis of the social dimension was conducted using the Multidimensional Scaling (MDS) approach based on several attributes, namely farmers' education level, family welfare, extension activities, participation in farmer groups, land conflict intensity, and household health status. The analysis results showed that the sustainability index value for the social dimension was 55.70, which falls within the moderately sustainable category (index interval of 50.01–75.00). These findings indicate that the economic sustainability of horticultural farming is relatively adequate, although improvements in several sensitive attributes are still required to enhance its sustainability performance. To evaluate the reliability of the MDS results, a Monte Carlo analysis was conducted at a 95% confidence level to detect potential errors during the analytical process. The Monte Carlo results were expressed as a Monte Carlo index value, which was subsequently compared with the MDS index value to determine the difference between the two analyses. Based on the Rapfish analysis, the difference between the MDS and Monte Carlo results at the 95% confidence level was relatively small, with a value of 0.7, which is less than 1. The small difference between these results indicates that the potential for estimation errors in the analysis can be minimized and that the sustainability assessment results can be considered reliable. Subsequently, a leverage analysis was conducted to identify the attributes that were most sensitive in influencing the sustainability of the social dimension. These sensitive attributes represent key factors that should be prioritized to improve the sustainability index of horticultural farming. The results of the leverage analysis for the social dimension are presented in the following figure.

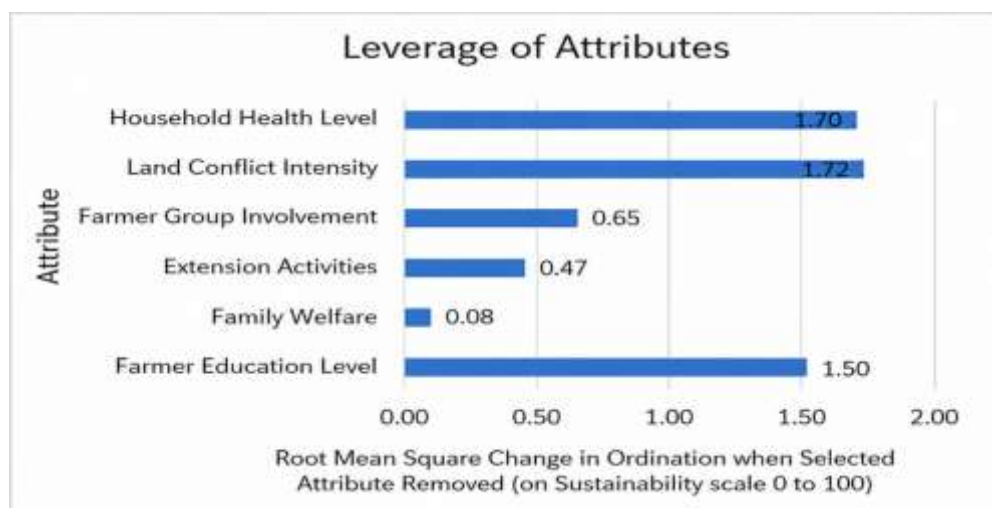


Figure 3. Leverage Analysis of Attributes in the Social Dimension

Based on the results of the leverage analysis, two attributes within the social dimension were identified as sensitive to the sustainability index, namely farmers' education level with an RMS value of 7.25 and land conflict intensity with an RMS value of 1.72. Farmers' education level was identified as the most sensitive attribute because education plays an important role in supporting farm management. Conditions in the study area indicate that the majority of farmers have only completed elementary school and junior high school education. This low level of educational attainment is attributable to the fact that many farmers did not pursue higher education or specialized education in agriculture. Furthermore, most farmers continue farming activities that have been inherited from their parents from generation to generation rather than being part of a new generation of competent young farmers. The declining interest of younger generations in entering the agricultural sector is likely due to the increasing number of farmers' children with higher educational attainment choosing to work in non-agricultural sectors, such as salaried employment or entrepreneurship (Le et al., 2020). A low level of education among farmers may hinder agricultural development and innovation adoption (Arief et al., 2025). In addition, land conflicts occur very rarely in the study area and can be considered almost nonexistent in relation to potato farming activities. Consequently, farming operations can be carried out under relatively conducive conditions. The limited land conflicts that occur in the study area generally involve issues related to land ownership, land boundaries, or management rights. Such disputes usually arise among family members. Land conflicts may occur when boundaries regarding access to resources or rights to resource use are not clearly defined, while at the same time there is a demand to maintain sustainability through resource utilization that may lead to conflict. Therefore, appropriate regulations should be established to prevent the occurrence of such conflicts in the future (Ratnasari et al., 2021).

Meanwhile the attribute with the lowest leverage value in the social dimension was family welfare (0.08). On average, farmers in the study area rely solely on income generated from their farming activities and generally do not have secondary occupations outside the agricultural sector. As a result, family welfare does not significantly influence increases or decreases in farmers' income levels (Nurmayanti et al., 2023). However, farmers with sufficient income tend to enjoy better levels of family welfare, whereas those with lower incomes often experience limitations in meeting their household needs.

3.2.2 Sensitive Attributes of the Ecological Dimension

The sustainability assessment of the ecological dimension was conducted using the Multidimensional Scaling (MDS) approach based on several attributes, including the condition and availability of clean water, crop quality, agricultural land conversion, pest and disease control, agricultural land management, and the use of chemical fertilizers. The analysis results showed that the sustainability index value for the ecological dimension was 57.23, which falls within the moderately sustainable category (index interval of 50.01–75.00). These findings indicate that the ecological aspects of potato farming are relatively sustainable; however, improvements in several sensitive attributes are still required to enhance sustainability performance. Therefore, the sustainability index of the ecological dimension can be improved through targeted interventions focusing on the most influential attributes. To evaluate the robustness of the MDS results, a Monte Carlo analysis was conducted at a 95% confidence level to detect potential errors in the analytical process. The results of this analysis were expressed as Monte Carlo index values, which were subsequently compared with the MDS index values to determine the differences between the two analyses. Based on the Rapfish analysis, the difference between the MDS and Monte Carlo results at the 95% confidence level was relatively small, with a value of 0.68, which is less than 1. The small difference between these results indicates that potential estimation errors in the analysis can be minimized, suggesting that the sustainability assessment results are reliable. Subsequently, a leverage analysis was conducted to identify the most sensitive attributes influencing the sustainability of the ecological dimension. These sensitive attributes represent key factors that

should be prioritized to improve the sustainability index of horticultural farming. The results of the leverage analysis for the ecological dimension are presented in the following figure.

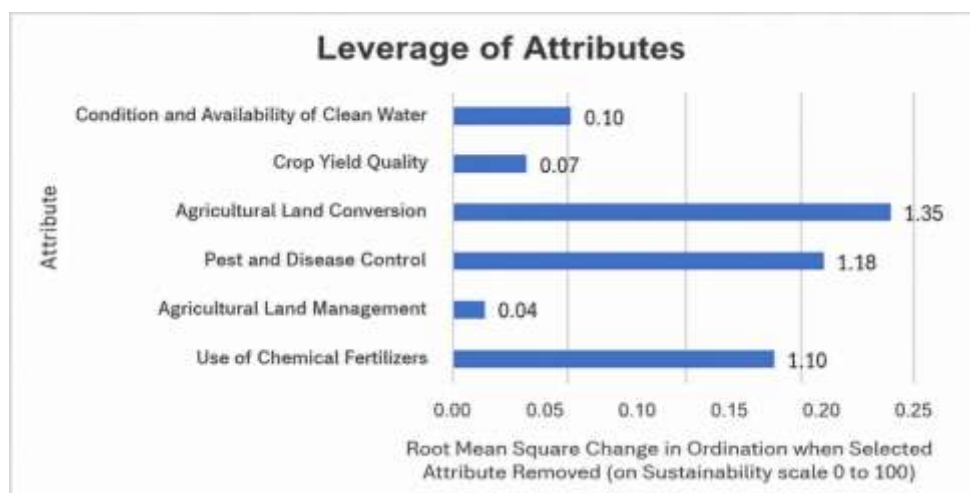


Figure 4. Leverage Analysis of Attributes in the Ecological Dimension

The values of sensitive attributes can be used to improve the sustainability index of the ecological dimension through efforts aimed at enhancing these attributes. Three attributes within the ecological dimension were identified as sensitive to the sustainability index of potato farming, namely agricultural land conversion (1.35), pest and disease control (1.18), and the use of chemical fertilizers (1.10). Agricultural land conversion in Indonesia remains relatively high and often occurs as a result of the expansion of non-agricultural sectors at the expense of agricultural land. In the study area, agricultural land conversion is also influenced by household needs, particularly when farmers face financial constraints related to farming capital or other family expenditures, such as children's education or marriage expenses. Consequently, farmers may have no alternative but to sell part of their agricultural land (Mawangsari et al., 2020). Therefore, controlling agricultural land conversion is one of the key efforts in achieving food security while improving the prosperity and welfare of farmers and society (Muryono et al., 2020).

Pest and disease control in the study area is primarily carried out using botanical pesticides, although some farmers still utilize chemical-based pesticides. In addition, pesticide application is generally limited and undertaken only under specific conditions to control severe pest infestations, either through the use of equipment or manual methods. Therefore, it is important for farmers to consider sustainable farming practices and alternative approaches for controlling pests and diseases in potato farming systems (Maryonno, 2018). The use of chemical fertilizers by farmers in the study area can be classified as moderate, with applications generally conducted twice per year. Fertilizer application practices are largely based on farmers' personal experience acquired through years of farming. Excessive use of chemical fertilizers not only has negative effects on soil health but may also adversely affect the surrounding environment. Therefore, it is important for farmers to consider sustainable farming practices and environmentally friendly fertilizer alternatives in order to maintain long-term agricultural sustainability (Erlinawati et al., 2022).

Meanwhile, the attribute with the lowest leverage value in the ecological dimension was agricultural land management, with a value of 0.04. Effective land management is influenced not only by natural conditions but also by farmers' skills and experience in farming activities. The majority of potato farmers in the study area have more than fifteen years of farming experience, enabling them to possess a relatively better understanding of cultivation techniques and greater expertise in managing their farming operations. However, in practice, farmers tend to focus primarily on increasing production output without adequately considering the environmental

impacts of their activities. One example observed in the study area is the construction of planting ridges (guludan) parallel to the slope gradient. This practice represents an inappropriate land management strategy because it can accelerate soil erosion, particularly during the rainy season (Finandayani et al., 2024).

CONCLUSION

The results of the study indicate that potato farming in Grogol Village, Pejawaran District, Banjarnegara Regency, is overall classified as moderately sustainable. All dimensions achieved relatively high index values, namely the economic, social, and ecological dimensions, which were categorized as moderately sustainable in supporting the sustainability of potato farming. Sensitive attributes were identified as important factors for formulating development strategies for potato farming in Grogol Village, Pejawaran District, Banjarnegara Regency. Within the economic dimension, the key attributes were production costs, access to capital, and farm income. Within the social dimension, the sensitive attributes were farmers' education level and land conflict intensity. Meanwhile, within the ecological dimension, the sensitive attributes included agricultural land conversion, pest and disease control, and the use of chemical fertilizers. On the other hand, attributes that were not considered priorities included market access in the economic dimension, family welfare in the social dimension, and agricultural land management in the ecological dimension.

Based on these findings, it is recommended that all indicators within each sustainability dimension be considered comprehensively as a basis for improving farming sustainability. Efforts to enhance farmers' capacity through training, experience, and the adoption of agricultural technologies should be continuously encouraged, accompanied by government support in the form of infrastructure development and farmer empowerment programs aimed at improving farming efficiency and productivity. Furthermore, future studies are recommended to undertake broader and more in-depth investigations so that various sustainability issues in farming systems can be analyzed more comprehensively.

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