Jurnal Manajemen & Agribisnis, Vol. 23 No. 1, March 2026
Permalink/DOI: http://dx.doi.org/10.17358/jma.23.1.96

Available online at
http://journal.ipb.ac.id/index.php/jmagr

COMPARATIVE SUSTAINABILITY EVALUATION OF GARLIC FARMING SYSTEM: THE ROLE OF INTEGRATION AND PARTNERSHIPS IN KARANGANYAR, INDONESIA

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Article history:

Received
28 October 2025

Revised
2 December 2025

Accepted
4 March 2026

Available online
31 March 2026

Abstract

Background: Garlic is a strategic horticultural commodity in Indonesia with diverse benefits and high market demand. However, the sustainability of garlic farming faces several structural challenges, including low productivity, limited market access, weak institutional support, low technology adoption, and poor quality seeds.
Purpose: This study aimed to evaluate the sustainability status of garlic farming, analyze performance differences, and identify sensitive attributes that influence sustainability.
Design/methodology/approach: This study was conducted in Karanganyar Regency with 120 respondents in total. This study used a Rapid Appraisal (RAP) method with a Multidimensional Scaling (MDS) approach.
Findings/Results: The results indicate that the multidimensional sustainability index of garlic farming is categorized as moderately sustainable (50–70). Farms adopting integrated farming with partnerships achieved the highest index (58.43), followed by non-integrated farms with partnerships (57.96), integrated farms without partnerships (54.61), and non-integrated farms without partnerships (54.17). The social dimension ranked the highest, followed by the ecological, economic, institutional, and technological dimensions. Leverage analysis identified 11 sensitive attributes, including farming experience, farmer group membership, water availability and conservation, marketing management, marketing institutions, seed availability, seed technology, bulb productivity, supporting policies, and organic fertilizer use. The simulation showed that improving these attributes could increase the multidimensional sustainability index by up to 26.76% in all categories.
Conclusion: Enhancing sustainability should focus on technology adoption, strengthening marketing institutions, improving seed access, and developing adaptive policies.
Originality/value (State of the art): This study shows that integrated interventions targeting these sensitive attributes are expected to facilitate the transition of garlic farming from “moderately sustainable” to “fully sustainable”.

Keywords: garlic, multidimensional scaling, RAP Analysis, influence sustainability, integrated farming

How to cite: Sundari, M. T., Rahayu, E. S., Irianto, H., Handayani, S. M., Setyowati, & Widadie, F. (2026). Comparative sustainability evaluation of garlic farming system: The role of integration and partnerships in Karanganyar, Indonesia. Jurnal Manajemen & Agribisnis, 23(1), 96. http://dx.doi.org/10.17358/jma.23.1.96

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INTRODUCTION

Garlic (Allium sativum L.) is an important commodity in Indonesia, widely used as a culinary spice, industrial raw material, and for medicinal purposes owing to its therapeutic properties (Hayat et al. 2022). Garlic plays a significant role in the national economy because of its influence on inflation (Saptana et al. 2021). Garlic consumption in Indonesia has continued to increase, with an average annual growth rate of 2.35% over the past decade (BPS, 2024). However, this high demand has not been matched by domestic production, which has shown a declining trend. In 2024, garlic production was recorded at 39,438 tons, which is far lower than the 81,805 tons produced in 2020 (BPS, 2025). Consequently, Indonesia has become heavily reliant on imports to meet its domestic needs. In 2023, Indonesia imported 564, 113 tons of garlic, making it the largest garlic importer in the world, with a global market share of 21.94% (FAO, 2024).

The Indonesian government has taken strategic actions to reduce import dependency through the National Garlic Self-Sufficiency Program (*Program Swasembada Bawang Putih Nasional*). Through this program, the government seeks to increase production by developing garlic production centers, including in the Karanganyar Regency of Central Java. Karanganyar is one of the largest garlic-producing regions in Central Java, along with Temanggung and Magelang. The local variety *Tawangmangu Baru* is recognized by its large bulb size and is regarded as a regional pride of Indonesia. From 2018 to 2023, garlic production in Karanganyar Regency showed an upward trend, peaking at 5,111 t. However, in 2024, production fell to 2,446 tons, a decline of 52.12% (BPS Jateng, 2025). This decline was not only due to the reduced harvested area, as productivity also decreased from 6.97 tons/ha to 6.04 tons/ha. This indicates that structural constraints affect the success and sustainability of garlic production development programs.

The success and sustainability of garlic production are influenced by complex and multidimensional factors. The dimensions of sustainability include social, ecological, economic, institutional, and technological aspects. Each dimension consists of multiple factors, ranging from production input use, management practices, and marketing challenges to price fluctuations, technological limitations, weak institutional support, and climate-related risks, all of which determine the sustainability of garlic farming (Mar'Atusholikha et al. 2019; Puspitasari et al. 2023). Therefore, a comprehensive evaluation incorporating multidimensional factors is essential. In particular, the sustainability of garlic development programmes is not only determined by assessing one sustainability determinant model but also by various other scenarios. Previous studies have not compared sustainability model scenarios with garlic production partnerships. We hypothesized that the sustainability status of garlic farming would differ significantly based on the application of integrated farming systems and the presence of partnerships, with the combination of both yielding the highest sustainability index.

The Rapid Appraisal for Fisheries (RAPFISH) multidimensional scaling technique was applied in this study because it enables a rigorous quantitative assessment of sustainability across multiple dimensions using an integrated set of indicators. RAPFISH is particularly suitable for comparing alternative policies or management scenarios, allowing researchers to identify leverage attributes that exert the greatest influence on sustainability performance and to simulate potential improvements resulting from targeted interventions.

This study aimed to evaluate the sustainability status of garlic farming in Karanganyar Regency and identify the key determinants influencing sustainable garlic farming in the region. Farms with integrated systems and partnerships are expected to demonstrate superior sustainability performance.

METHODS

This study employed cross-sectional primary data collected through structured interviews with garlic farmers across multiple production centers in the Karanganyar Regency. The primary dataset captures detailed quantitative and qualitative information on socioeconomic characteristics, farming practices, institutional engagement, technological adoption, input–output performance and environmental management. The cross-sectional nature of the data allows for a comparative assessment of sustainability status at a specific point in time while minimizing temporal variations, thereby enabling a comprehensive evaluation of the systemic determinants affecting the sustainability performance of garlic farming in the region. The use of direct farmer responses ensures high contextual accuracy and reflects the real conditions faced by producers in the field, thereby reducing reliance on secondary assumptions. Furthermore, the dataset provides a robust empirical foundation for multidimensional sustainability analyses and supports evidence-based decision-making by agricultural stakeholders and policymakers in the region.

A total of 120 farmer respondents were selected using a simple random sampling approach and classified into four distinct categories according to their level of production integration and partnership arrangements. These categories were as follows: (1) integrated farming with partnerships, (2) integrated farming without partnerships, (3) non-integrated farming with partnerships, and (4) non-integrated farming without partnerships.

The sustainability of garlic farming was analyzed using the Rapid Appraisal (RAP-Analysis) method, better known as the RAPFISH method (Alder et al. 2000; Pitcher, 1999; Pitcher & Preikshot, 2001). RAPFISH is a sustainability evaluation method based on the ALSCAL MDS (Multidimensional Scaling) algorithm (Fauzi, 2019). This approach can be used to determine the condition or sustainability status of an economic system and its activity. In this study, the application of RAPFISH was adjusted to the Rapid Appraisal for Garlic (RAP-Garlic) method (Puspitasari et al. 2023). The analyzed dimensions were based on the pillars of sustainable development: social, ecological, economic, institutional, and technological dimensions. A total of 41 attributes (indicators) were used to evaluate the sustainability of garlic farming, as presented in Table 1.

The sustainability status of garlic farming was determined using multidimensional scaling (MDS). Values between 0 and 25 indicate unsustainable, 25–50 indicate less sustainable, 50–75 indicate moderately sustainable, and 75–100 indicate sustainable (Stanny et al. 2021; Widjaja et al. 2024). Leverage analysis was used to determine the most sensitive attributes that can serve as sustainability “leverage” factors. Three approaches are used to determine sensitive attributes: (1) the extreme value rule, which selects attributes with the most prominent values; (2) the mean value rule, which selects attributes with above-average values; and (3) the Pareto optimum rule, which selects attributes based on the Pareto principle or the 80:20 rule (Yusuf et al. 2021).

Table 1. Attributes/indicators of each sustainability dimension

Dimensions	Attributes / Indicators	
Social	1.1. Farming experience	1.6. Labour availability
	1.2. Groups membership	1.7. Farmer’s age
	1.3. Labour planning	1.8. Perception of integration
	1.4. Activeness in farmer groups	1.9. Risk management strategy
	1.5. Information from extension	
Ecology	2.1. Water availability	2.5. Climate change risk
	2.2. Water conservation	2.6. Pest risk
	2.3. Climate suitability	2.7. Frequency of pest attacks
	2.4. Frequency of disease attacks	2.8. Impact of pest and disease attacks
Economics	3.1. Marketing management	3.7. Harvest price
	3.2. Seeds availability	3.8. Post-harvest management
	3.3. Bulb productivity	3.9. Financial impact of crop failure
	3.4. Farming costs	3.10. Capital availability
	3.5. Land ownership	3.11. Income
	3.6. Resource access risk	3.12. Price risk
Institutional	4.1. Marketing institutions	4.4. Role of farmer’s group
	4.2. Supporting policies	4.5. Role of farmer’s associations
	4.3. Post-harvest management support	4.6. Capital access
Technology	5.1. Use of organic fertilizers	5.4. Post-harvest technology response
	5.2. Application of seed technology	5.5. GAP technology mastery
	5.3. Application of cultivation technology	5.6. Application of post-harvest technology

Source: Bathaei & Štreimikienė (2023), FAO (2013), Latruffe et al. (2016), Mar’Atusholikha et al. (2019), Puspitasari et al. (2023), Riptanti et al. (2022), Siregar (2025), Stanny et al. (2021), Widjaja et al. (2024), Wohlenberg et al. (2022)

Based on Figure 1, this study presents a comprehensive conceptual framework for evaluating the sustainability of garlic farming in Karanganyar by integrating five interrelated dimensions: ecological, social, economic, technical, and legal–institutional. Indicators derived from authoritative sources, such as the FAO and Rapfish, were synthesized into measurable scores and attributes, which enabled a systematic assessment of sustainability across four farming system classifications: integrated–partnership, integrated–non-partnership, non-integrated–partnership, and non-integrated–non-partnership. These indicators form the basis for determining the sustainability status and conducting an in-depth sustainability analysis of garlic farming in the region. The outcomes of this analytical process subsequently inform evidence-based policy recommendations aimed at enhancing the long-term resilience, efficiency, and institutional robustness of garlic production in Karanganyar, Central Java, Indonesia.

RESULTS

Sustainability of Garlic Farming

The suitability of the sustainability model was evaluated using stress values, R^2, and Monte Carlo simulations. An accurate and reliable model should have a stress value < 0.25, an R^2 value close to 1, and stable Monte Carlo simulation results (Fauzi & Anna, 2002; Kavanagh & Pitcher, 2004; Pitcher et al. 2013). Table 2 shows that the developed model has a stress value of < 0.25 across all sustainability dimensions.

The coefficient of determination (R^2) values were greater than 0.9 for all dimensions, indicating that the attributes/indicators used effectively explained the sustainability of garlic farming. The level of random error in the model was analyzed using a Monte Carlo simulation with a 95% confidence level. The Monte Carlo simulation results in Table 3 show no significant difference (sig. > 0.05) between the sustainability index values generated by the MDS analysis and those from the Monte Carlo simulation. This indicates that the model has high accuracy in assessing the sustainability of garlic farming.

The results of the RAP-Garlic model analysis presented in Table 2 show that the sustainability status of garlic farming varies across dimensions and categories. Although all categories of garlic farming have a multidimensional sustainability index ranging from 50 to 70, which is classified as moderately sustainable, the four categories are at different levels. Garlic farming that applies an integrated farming system with partnerships has the highest sustainability index of 58.43, followed by non-integrated farms with partnerships (57.96), integrated farms without partnerships (54.61), and non-integrated farms without partnerships (54.17).

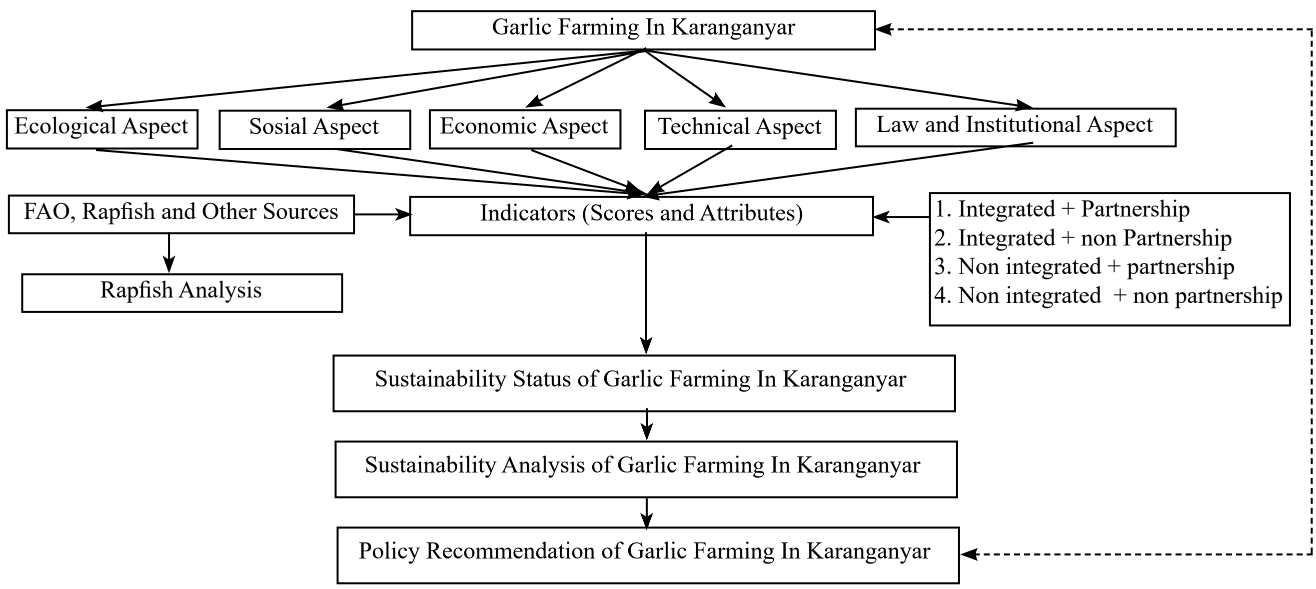


Figure 1. Framework of sustainability evaluation of garlic farming using an integrated farming system

Table 2. Comparison of sustainability index of garlic Farming in Karanganyar Regency

	Integration (Partnership)	Integration (Non- Partnership)	Non- Integration (Partnership)	Non- Integration (Non- Partnership)	Stress	R^2
Social	80.69	71.17	78.66	68.89	0.135	0.993
Ecology	72.77	67.59	71.52	70.50	0.116	0.956
Economics	55.61	55.72	56.00	54.86	0.182	0.902
Institutional	52.96	49.21	53.63	46.90	0.208	0.905
Technology	30.09	29.35	30.00	29.69	0.060	0.998
Multidimension	58.43	54.61	57.96	54.17	0.140	0.951
Status	Moderately Sustainable	Moderately Sustainable	Moderately Sustainable	Moderately Sustainable		

Table 3. Validation of sustainability index with monte carlo analysis

	Integration (Partnership)	Integration (Non- Partnership)	Non- Integration (Partnership)	Non- Integration (Non- Partnership)	Mean Difference	Sig. (2-tailed)
Social	73.79	68.48	69.38	67.84	4.98	0.185
Ecology	69.15	65.20	68.54	67.43	3.02	0.078
Economics	57.34	58.24	60.86	56.28	2.63	0.071
Institutional	51.86	49.23	58.29	49.12	1.45	0.609
Technology	31.37	30.08	33.65	33.64	2.40	0.070

At the inter-dimensional level, integrated farming systems with partnerships have advantages in the social, ecological, and technological dimensions, whereas non-integrated garlic farming with partnerships has advantages in the economic and institutional dimensions. The implementation of an integrated farming system combined with partnerships can increase resource efficiency and ecosystem services, as well as improve access to inputs, markets, technology transfer, and other capital support, thereby enhancing farming sustainability (Li & Wang, 2024; Sultan et al. 2024; Widjaja et al. 2024).

The sustainability index of garlic farming in Karanganyar Regency is still higher than that of garlic farming in Temanggung Regency, which is 25.38 (Puspitasari et al. 2023), but lower than that of garlic farming in Tegal Regency, which is 66.44 (Mar'Atusholikha et al. 2019). This indicates the need for effective strategies to improve the sustainability performance of garlic farming in Karanganyar Regency.

The kite diagram in Figure 2 shows a visualization of the comparison of sustainability levels across dimensions in each farming category. In general, all categories of garlic farming have a similar order of sustainability levels among dimensions. The social dimension has the highest level of sustainability in all categories. The ecological dimension ranks second, followed by the economic, institutional, and technological dimensions. The uniformity of profiles in the four categories indicates that the classification of farming based on the application of the integrated farming system and the existence of partnerships do not change the structural factors that determine the partial performance among sustainability dimensions of garlic farming. This means that there are dominant determinants which systemic and influence all sustainability dimensions, resulting in relatively small differences among categories. This result consistents with the findings of Sayaka et al. (2021) and Azis & Suryana (2024), the challenges of garlic production in Indonesia are cross-locational and stem from various other structural problems. Puspitasari et al. (2024) emphasized the interconnection of these factors, and when these determinants are strong and macro in nature, the problems will affect all farmers and their performance across all production clusters.

Leverage Analysis

1. Social Dimension

The sustainability performance of the social dimension of garlic farming in Karanganyar Regency was the highest among all the dimensions. Two categories of garlic farms are classified as sustainable in this dimension: farms applying the integrated farming system with partnerships, with an index of 80.69, and non-integrated farms with partnerships, with an index of 78.66. Meanwhile, integrated farms without partnerships had a social sustainability index of 71.17, and non-integrated farms without partnerships scored 68.89, both categorized as moderately sustainable in the social dimension. Horticultural farming, including garlic farming, is often managed by farming communities and families that maintain labor, local knowledge, and cooperation networks. Sannou et al. (2023) emphasized that social aspects are often easier to sustain at the community level because of the strong local norms and networks. High sustainability performance in the social dimension can serve as an important asset for formulating strategies and designing interventions to enhance overall sustainability. Strong social capital facilitates innovation adoption when properly utilized.

Figure 3 shows the most sensitive attributes within the social dimension supporting the sustainability of garlic farming in Karanganyar Regency, namely, farming experience and membership in farmer groups. Garlic farmers in Karanganyar generally possess extensive experience, having cultivated garlic for an average of more than eight years across all farming categories. Farming experience reflects farmers' knowledge and skills in managing their farms. This indicates that maintaining the quality of farmers' knowledge and skills is essential, even when farms are managed by farmers of varying ages or are transferred to the next generation. Utami et al. (2023) found that farmers generally acquire knowledge from their parents, fellow farmers, experience, and observation. Therefore, knowledge and skill sharing among farmers is crucial for maintaining the quality of farm management.

Farmers cannot be separated from the groups that influence their knowledge, skills, and perspectives in managing their farming activities (Prayoga et al. 2021). Farmer groups serve as platforms for farmers to socialize and collaborate on various activities. The analysis shows that most garlic farmers in the partnership categories, both integrated (93%) and nonintegrated (92%), are members of farmer groups. Conversely, in the non-partnership categories, only 55% and 42% of farmers were members. Therefore, raising awareness among non-member farmers about the importance of group participation and the benefits of being active within farmer groups is essential to increase garlic farmers' engagement in such organizations.

2. Ecological Dimension

The ecological dimension ranked second, with a moderately sustainable status for all garlic-farming categories. The ecological sustainability index for all categories was relatively similar at 72.77, 67.59, 71.52, and 70.50, respectively. This indicates a comparable level of environmental support capacity and farmers' awareness of maintaining ecosystems. The application of integrated farming systems or partnerships has not directly improved the ecological performance of garlic farming in Karanganyar Regency.

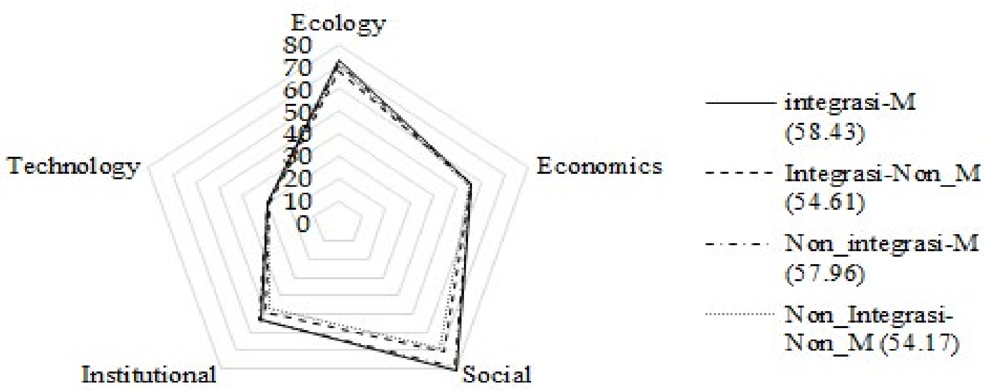
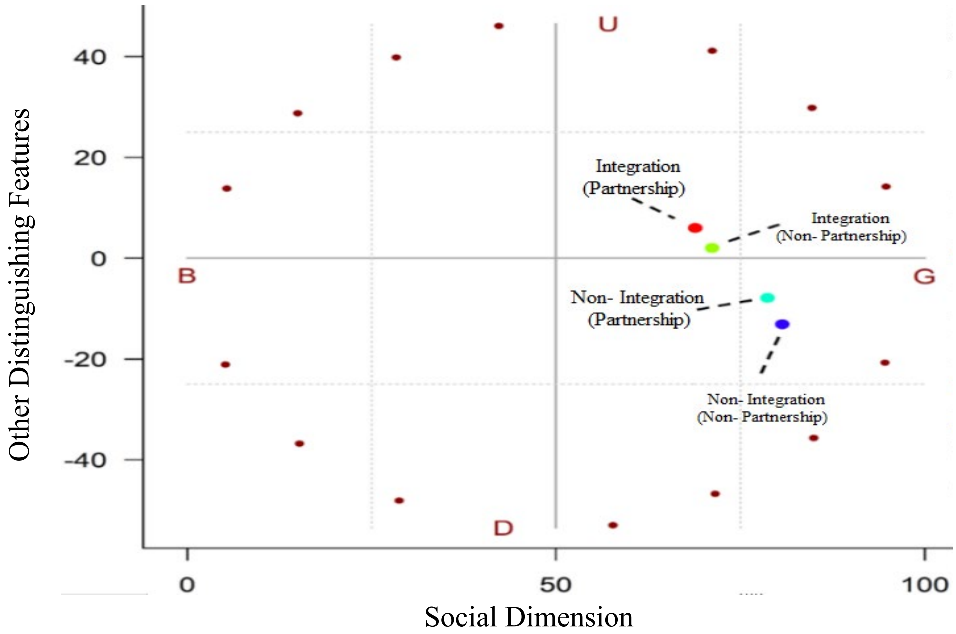


Figure 2. Kite Diagram of the sustainability index of garlic farming in Karanganyar Regency



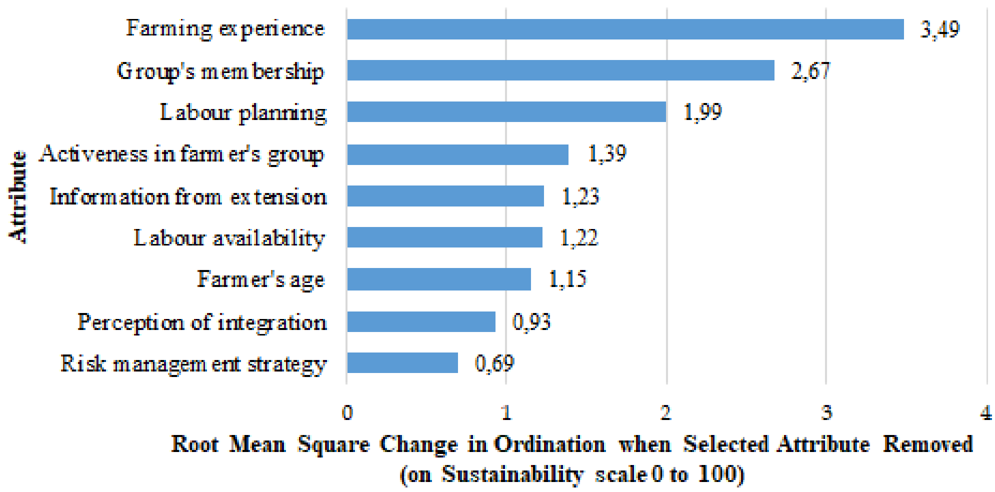


Figure 3. Ordination and leverage of attributes in the social dimension of garlic farming

Based on the analysis in Figure 4, the ecological dimension has two attributes: availability and water conservation. The analysis shows that water availability for garlic farming in Karanganyar is both abundant and sufficient. This condition supports the success of garlic cultivation in this region. Garlic requires an adequate water supply for optimal growth in terms of both quantity and timing (Hanson et al. 2003; Sahu et al. 2023). Adiwijaya et al. (2022) and Ayele et al. (2023) confirmed that the volume and frequency of irrigation significantly affect garlic yields. However, irrigation must be carefully managed to avoid wastage. In areas with high rainfall, poor soil drainage may lead to stem rot and Fusarium disease, which are major problems in garlic cultivation (Adiwijaya et al. 2022). Therefore, proper irrigation management and systems are essential for maintaining ecological balance, which, in turn, affects the sustainability of garlic farming in the region. Another sensitive attribute is water conservation, which is highly relevant to this study. Implementing water conservation and proper drainage practices should be prioritized to maintain the ecological functions of garlic farmlands and to support sustainable production. Practices such as improving drainage and constructing water storage ponds positively affect water availability and production stability. The analysis shows that most garlic farmers in Karanganyar already practice water conservation, although a small proportion do not practice it. This finding indicates that conservation practices should be maintained and reinforced. Additionally, precision farming techniques, such as drip irrigation systems, can be applied to improve water use efficiency (ICID, 2022)

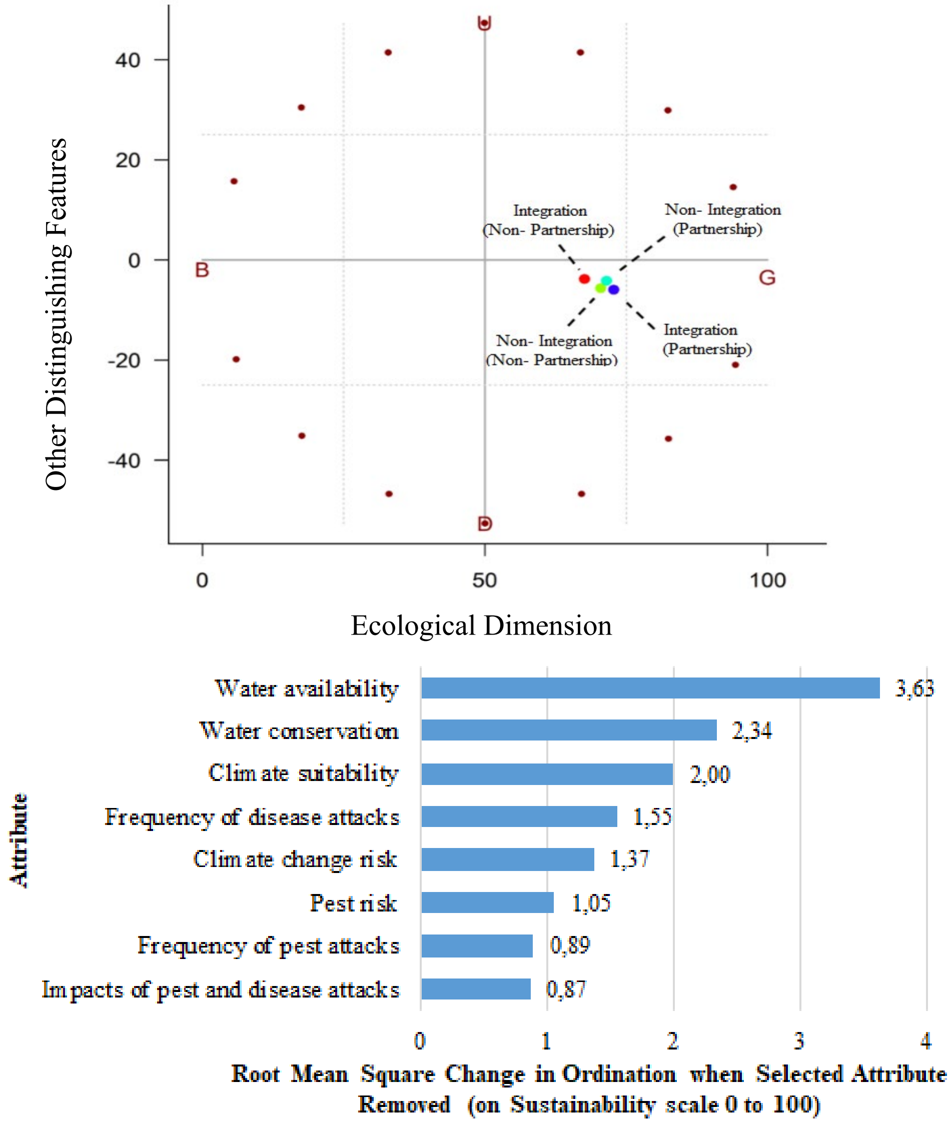


Figure 4. Ordination and leverage of attributes in the ecological dimension of garlic farming

3. Economic Dimension

The sustainability performance of the economic dimension ranked third, with index values that did not differ significantly among the garlic farming categories (55.61, 55.72, 56.00, and 54.86), indicating a moderately sustainable status. Many garlic farmers operate on a small scale, which limits their access to credit, insurance, and post-harvest infrastructure. These constraints can hinder profitability and increase the business risk. Touch et al. (2024) highlight that financial limitations can suppress the economic performance of agricultural enterprises. This condition indicates that interventions aimed at improving access to financial services, providing input subsidies, and investing in post-harvest facilities are crucial to reducing the economic vulnerability of garlic farmers

The leverage attributes influencing economic sustainability include marketing management, seed availability, and bulb productivity (Figure 5). Weak marketing management makes farmers dependent on middlemen or traditional distribution channels, which often provide limited value-added products. The analysis shows that 80% of garlic farmers in Karanganyar Regency sell their harvests directly to middlemen. Farmers have not yet implemented a structured marketing management system. Core marketing functions such as planning, promotion, pricing, and evaluation are still largely absent. Farmers have not developed effective marketing networks to sell their products. Therefore, interventions to strengthen market access, improve price transparency, and develop supply chains are crucial in this regard. Farmers need training in marketing planning, pricing, networking, and system evaluation to enhance the competitiveness, profitability, and overall sustainability of garlic farming.

Seed availability and bulb productivity are interrelated attributes. High-quality and reliable seeds directly contribute to increased crop productivity and yield stability. Conversely, limited access to quality seeds can lead to low productivity, high production costs, and reduced market competitiveness. The findings revealed that 60–70% of farmers use seeds from their own harvests, indicating that strengthening the economic sustainability of garlic farming must begin upstream through the provision of high-quality, affordable, and easily accessible seeds to ensure adequate seed supply at the farm level. Moreover, proper seed handling and storage techniques are needed to maintain seed quality and achieve the desired bulb productivity. The use of certified and sanitized seeds is essential for sustaining garlic-bulb productivity. Fertilization practices and fertilizer combinations significantly affect garlic productivity (Abrham et al. 2024).

4. Institutional Dimension

The institutional dimension of garlic farming in Karanganyar Regency ranges from less sustainable to moderately so. The sustainability index values for the institutional dimension are 52.96, 49.21, 53.63, and 46.90, respectively. Although partnerships exist and are practiced by farmers, their quality, capacity, and continuity are weak. Some partnerships are transactional rather than transformational in nature. Unstructured or unsustainable partnerships have a limited impact on the institutional performance of farming enterprises (Alotaibi & Kassem, 2022; Sjaf et al. 2022).

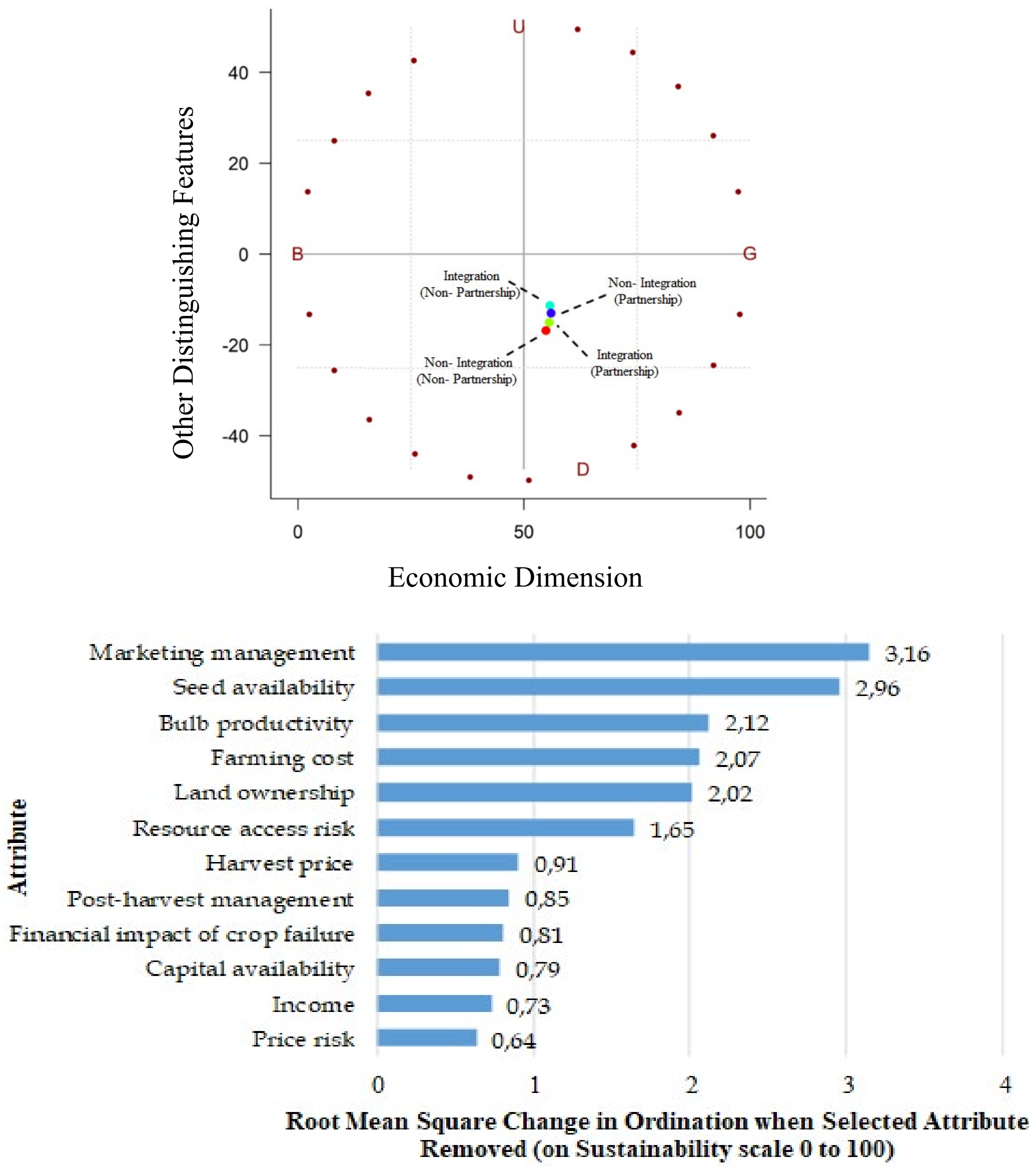


Figure 5. Ordination and leverage of attributes in the economic dimension of garlic farming

This indicates that strengthening institutional capacity is essential for efforts to improve the sustainability of garlic farming to have a significant impact. Institutional strengthening requires improvements in the organizational structure of farmers, consistent regulatory support, incentives for agribusiness partners, and the development of broader and more sustainable market networks. Thus, institutions can function as a driving force of innovation, strengthen farmers' bargaining positions, and ensure the continuity of partnerships in the agricultural sector.

The leverage analysis results in Figure 6 show that the most sensitive attributes in the institutional dimension are marketing institutions and policies. This finding is consistent with the economic dimension analysis, which identified marketing management as the most sensitive leverage attribute for improving the sustainability of garlic farming in the Karanganyar Regency. This emphasizes that the success of garlic farming is not solely supported by the technical aspects of production but is also strongly influenced by efficient marketing, institutional governance and the alignment of public policies.

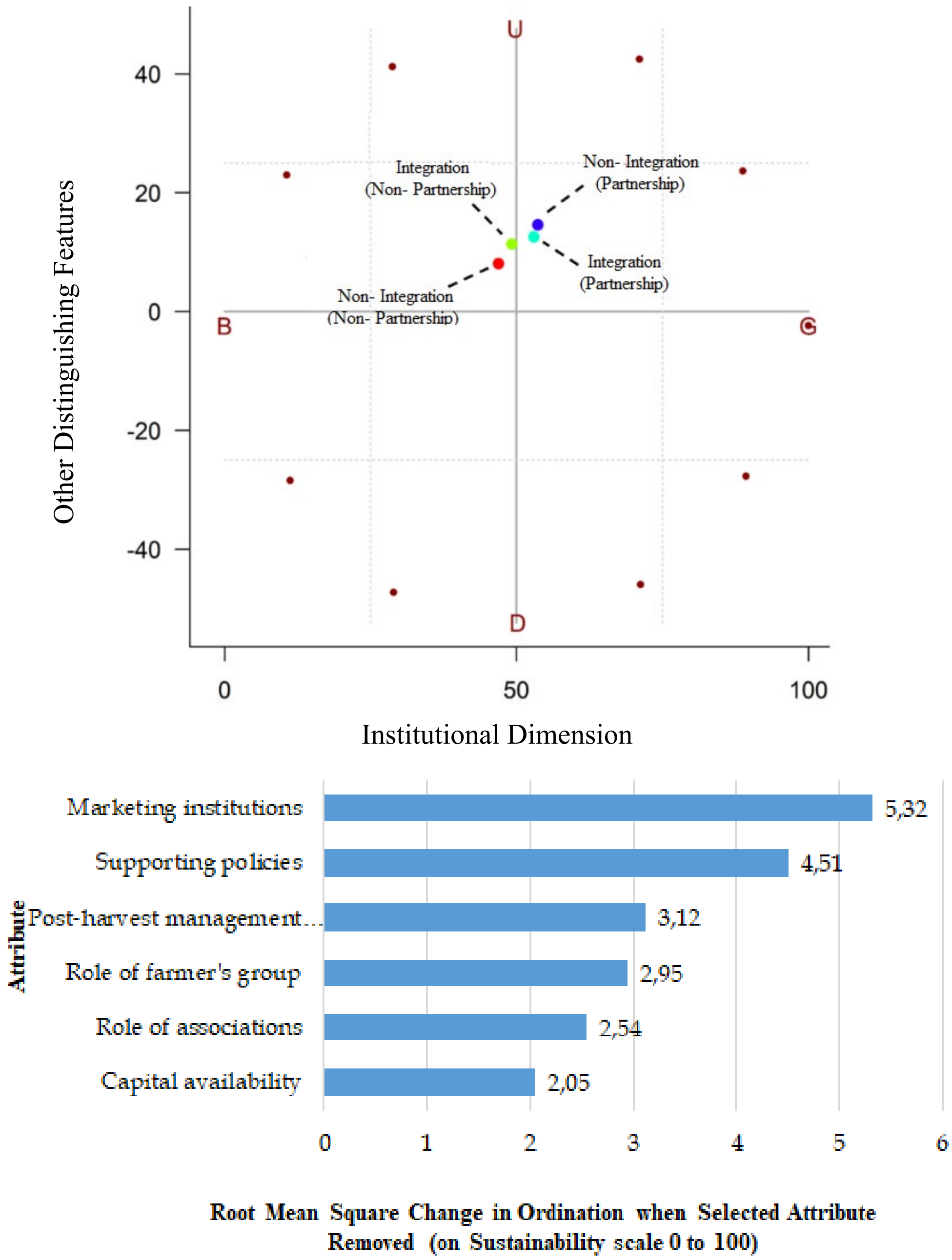


Figure 6. Ordination and leverage of attributes in the institutional dimension of garlic farming

The analysis shows that less than 10% of garlic farmers in Karanganyar Regency have experienced the role of marketing institutions in their garlic sales. Therefore, strategic interventions through strengthening collective marketing systems, adaptive regulatory support and improved market access are essential. Collective marketing systems can enhance the development and sustainability of farming enterprises by providing formal and informal market access (Magakwe & Olorunfemi, 2024). These findings highlight the crucial role of marketing institutions in improving the sustainability of farming systems.

Supportive policies also play an important role in garlic farming sustainability. However, farmers report that they have not yet felt the tangible benefits of either national or local policies owing to issues in implementation, access, and institutional capacity. The analysis shows that 47.5% of garlic farmers believe that there are no specific policies supporting garlic farming, while 50.8% acknowledge the existence of policies but feel that the benefits have not been realized. Fatimah & Muhafidin (2024) explain that agricultural programs and policies often fail to reach small-scale farmers effectively due to bureaucratic barriers and poor targeting, making it difficult for them to access policy benefits. Policies designed to support farmers do not automatically improve their welfare or farming sustainability. This means that policies must be accompanied by strengthening the implementation of institutions at the local level so that their impact can be directly felt by farmers.

5. Technological Dimension

The sustainability index for the technological dimension was the lowest. All categories of farming showed index values between 25 and 50, specifically 30.09, 29.35, 30.00, and 29.69, indicating a less sustainable status. This condition is common in the agricultural sector, where technology adoption tends to be slow and uneven. Behavioral differences, economic constraints, and technical factors such as knowledge, initial costs, and perceived risks are key factors that hinder technology adoption among small-scale farmers (Chacko, 2024). Technologies in garlic farming, including seed technology, cultivation techniques, and post-harvest technologies, require both investment and technical expertise, which are often difficult to access.

The leverage analysis in Figure 7 shows that the most sensitive attributes in the technological dimension are the use of organic fertilizer and the application of seed technology. Organic farming practices have been proven to yield better results than conventional farming systems. Several studies have confirmed that the use of organic fertilizers can significantly increase garlic production (Negi et al. 2024; Singh et al. 2025). Furthermore, Pacini et al. (2003) demonstrated that organic farming systems perform better and support sustainability in agriculture. Conversely, excessive use of chemical fertilizers leads to soil saturation, reduced fertility, and a decline in garlic bulb quality (Puspitasari et al. 2023). Balanced fertilization with organic inputs can enhance cation exchange capacity and nutrient absorption (Kusumarini et al. 2020), thereby restoring and improving soil quality and ecological capacity to achieve better sustainability performance.

The application of seed technology is another key leverage attribute in this regard. This finding aligns with Mardiana et al. (2021), who emphasized that the use of high-quality superior seed varieties is a significant factor in achieving optimal garlic production. The average productivity of garlic in Karanganyar Regency is 6.04 tons/ha (BPS Central Java, 2025), which is below the national average of 7.4 tons/ha (BPS, 2025). The use of farmer-saved seeds is one of the main causes of declining productivity and garlic quality in the region.

Vegetative seed propagation methods cause uncertain varietal purity, low seed germination rates, uneven plant growth, reduced yields, and the potential spread of viruses (Pardian et al. 2019; Sayaka et al. 2021). From an economic perspective, seed use represents the most significant expenditure in total production costs, making the provision of affordable seeds one of the key determinants of garlic farming sustainability (Kiloes & Hardiyanto, 2020). This highlights the importance of supporting seed technology development programs for breeders and seed producers to generate high-quality garlic seed varieties.

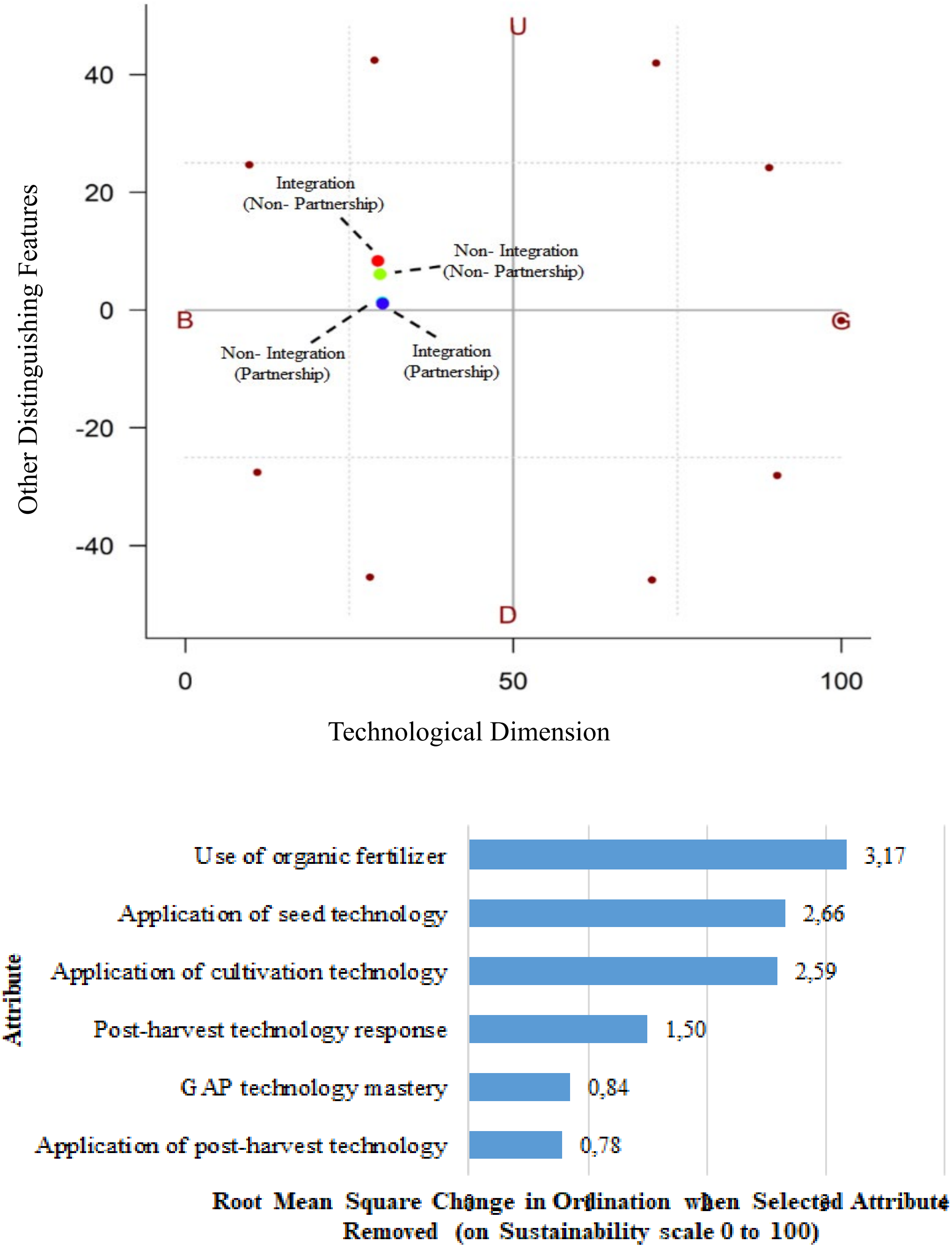


Figure 7. Ordination and leverage of attributes in the technological dimension of garlic farming

Strategies to Improve Sustainability

Strategies must be implemented across all dimensions to enhance the sustainability of garlic farming. Strategies should focus on sensitive attributes or indicators that significantly enhance the sustainability performance of garlic farming. A total of 11 attributes were selected based on leverage analysis, followed by simulations that maximized these attributes to observe improvements in sustainability performance.

The strategies that can be implemented to optimize the sensitive attributes from the five dimensions include farming experience, farmer group membership, water availability, water conservation, marketing management, seed availability, bulb productivity, marketing institutions, supportive policies, use of organic fertilizers, and application of seed technology (Table 4).

Table 4. Simulation results of the implementation of sustainability improvement strategies on garlic farming in Karanganyar Regency

	Integration (Partnership)		Integration (Non- Partnership)		Non- Integration (Partnership)		Non- Integration (Non- Partnership)	
	Index	Change (%)	Index	Change (%)	Index	Change (%)	Index	Change (%)
Social	81.80	1.37	77.75	9.25	80.52	2.36	77.48	12.47
Ecology	76.57	5.21	76.31	12.91	77.00	7.67	75.99	7.79
Economics	71.94	29.36	72.45	30.03	71.66	27.98	71.96	31.18
Institutional	74.43	40.52	70.32	42.90	74.87	39.61	69.10	47.32
Technology	50.35	67.31	47.93	63.34	50.39	67.95	48.77	64.29
Multidimension	71.02	21.55	68.95	26.27	70.89	22.30	68.66	26.76

Managerial Implication

The moderate sustainability performance observed across all garlic farming categories in Karanganyar Regency underscores the need for strategic, systemic interventions rather than fragmented and category-specific approaches. Given that integrated farming systems supported by formal partnerships achieved the highest sustainability index, stakeholders (local government agencies, extension institutions, and agribusiness partners) should prioritize scaling out and institutionalizing this model to enhance both productivity and resilience. The eleven leverage attributes identified through the analysis represent critical managerial entry points with high transformative potential. Strengthening farmer experience and organizational participation can enhance knowledge diffusion and collective problem-solving, while securing water availability and promoting conservation practices are essential for maintaining ecological stability amid increasing climatic variability. Improving seed availability, seed technology adoption, and bulb productivity should form the backbone of technological upgrading initiatives. Concurrently, reinforcing marketing institutions and management capacities can stabilize value chain performance and increase farmers' bargaining power. Supportive policy frameworks must be continuously refined to incentivize sustainable input use, particularly organic fertilizers, and to facilitate technology dissemination. If these leverage points are addressed cohesively, the multidimensional sustainability index could increase substantially up to 26.76%, providing strong evidence that targeted managerial actions can significantly strengthen the long-term viability and competitiveness of the garlic farming sector in Karanganyar

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Garlic farming in Karanganyar Regency, in a multidimensional context, has a sustainability index ranging between 50–70, categorized as moderately sustainable across all farming categories. Farms implementing integrated farming systems with partnerships achieved the highest performance with an index of 58.43, followed by non-integrated with partnerships (57.96), integrated without partnerships (54.61), and non-integrated without partnerships (54.17). This moderate sustainability status, while higher than that reported in Temanggung, remains below the performance in Tegal, underscoring the need for targeted interventions. The relatively similar profiles among categories indicate the presence of systemic determinants that affect all farmers. Among the five dimensions, the social dimension performed best, followed by ecological, economic, institutional, and technological dimensions. The leverage analysis identified 11 key leverage attributes, namely: farming experience, farmer group membership, water availability, water conservation, marketing management, seed availability, bulb productivity, marketing institutions, supportive policies, use of organic fertilizers, and seed technology application. The simulation of improving these attributes showed a significant increase in the multidimensional sustainability index of up to 26.76%. These findings reinforce theoretical understanding that sustainability is not unidimensional but require a systemic approach, demonstrating that social and ecological capital can serve as a foundation upon which to build improvements in weaker economic, institutional, and technological dimensions.

Recommendations

Strong social capital and favorable ecological conditions support substantial sustainability improvements, especially when accompanied by integrated policy interventions to promote sustainable garlic farming in Karanganyar Regency.

CONFLICT OF INTEREST: The authors declare no conflict of interest

FUNDING STATEMENT: We would like to express our sincere gratitude to Sebelas Maret University as the funder through the 2025 Non-State Budget Research Grant Program, Group Research Grant, with Contract Number 371/UN27.22/PT.01.03/2025.

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